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ABSTRACT

This unit, one of a series designed to develop and foster an understanding of the marine environment, presents marine science activities for students in grades 9-12. The unit, focusing on physical factors influencing life in the sea, is divided into sections dealing with: (1) the ocean floor; (2) tides; (3) ocean waves; (4) ocean currents; (5) pressure; and (6) sea water. Each section has a student text (including several readings from "Scientific American") with related activities. Each student text is preceded by a teacher background section containing hints on how to use the section, additional information, and items requiring advanced planning. Each activity is also preceded by a teacher background section providing additional information about the activity, including teaching hints and answer key for activities. Important vocabulary words/terms are listed in the teacher background sections; they are also underlined in the student text. Activities are designed to enhance reading as well as investigational skills; several activities provide practice in mathematics skills. Although all activities can be modified to suit individual needs or be used "as is," it is strongly recommended that they be performed along with the readings/discussions found in student text material. (JM)

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9-12 MARINE BIOLOGY AND OCEANOGRAPHY

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Marine Science Center

PART I

SE043319

MARINE BIOLOGY AND OCEANOGRAPHY

GRADES NINE TO TWELVE

MARINE SCIENCE CENTER
C. David Borden, Director
North Kitsap School District No. 400
Poulsbo, Washington 98370

ESEA TITLE IV-C

James A. Kolb
Project Developer
Author/Editor

MARINE BIOLOGY AND OCEANOGRAPHY

GRADES NINE TO TWELVE

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MARINE BIOLOGY AND OCEANOGRAPHY

GRADES NINE TO TWELVE

INTRODUCTION

The history of the United States is strongly tied to the seas. The future of the United States will also be strongly tied to the marine world. It is important that the leaders and the citizenry alike have a familiarity with the marine environment that will permit them to make wise choices in resolving the conflicts that are sure to arise over use of the ocean's resources. Marine Biology and Oceanography is designed to contribute to the knowledge necessary to make these sound decisions. In the development of Marine Biology and Oceanography, our goal has been to provide an opportunity for both the teacher and the student to become aware of the living and non-living factors that shape the life of the sea.

As the title implies, Marine Biology and Oceanography is presented in two units. The first unit, Oceanography, deals with the physical factors that influence life in the sea. Marine Biology treats the plants and animals of the sea and their interactions with each other and with the non-living environment. The divisions between the units are arbitrary and not strictly maintained. Each unit has been designed to be used in its entirety or just in part. It is recommended that the teacher incorporate his or her own ideas, experiences, and background to elaborate the subject material. It is important to develop the natural enthusiasm students have for learning about the sea. This is the time to add a bulletin board dealing with the marine world to your classroom. Displays of living and non-living marine creatures are also recommended. Use your imagination to create an exciting classroom atmosphere. National Geographic magazines are excellent sources of pictures. Incorporate some of the books listed in the "Bibliography of Selected Books about the

Marine Environment" section into your reading program. Investigate the audio-visual materials available from your supplier. Have students bring in their shell collections and other related items. These units have the potential for not only being worthwhile, they can be fun!

Each unit is divided into several sections. Each section has a student text and student activities. Each student text is preceded by a "Teacher Background" section which contains: hints on how to use the section, additional information, and items for which advanced planning is required. Important vocabulary terms are listed in the "Key Word" section of each "Teacher Background." They are also underlined in the text. The words are defined in the text, either directly or by context. All of the sections have activities accompanying the text. Most activities require few materials not ordinarily found in secondary science classrooms. It is strongly recommended that the activities be performed along with the reading and discussion of the text. Each activity is also preceded by a "Teacher Background" section. This section gives additional information about the activity including teaching hints and answer key. The activities are designed to enhance reading skills as well as investigational skills. Some activities provide practice in math skills. The activities can be modified to suit your particular needs, but will work "as is."

Skim the contents of the units to discover the organizational scheme. Please read the text and activities before you use them. The materials have all been prepared with ease of duplication in mind. Please feel free to duplicate any and all materials you need to effectively utilize this unit with your class.

Many of the laboratory experiences originated or have been utilized at the Marine Science Center. Teachers using these materials are given the opportunity to use the many resources available through the Marine Science Center staff. Our staff is available to you to give assistance in providing resource material and in setting up the unit of study. Please feel free to contact one of our staff members by calling (206) 779-5549.

At the end of the text and activity section, you will find a "Send-in Page." We would like you to use it to let us know how much you liked or disliked the units. If you have some marine activity that you have tried successfully with your students, please let us know about it. Perhaps we can incorporate it in future revisions.

This unit is one of a series designed to develop and foster an understanding of the marine environment. Other units in the series include:

Marine Science Activities, Grade 2
Marine Science Career Awareness, Grade 4
Marine Science Activities - The Marine Environment, Grade 6
Marine Biology and Oceanography, Grades 7 - 9

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James A. Kolb
Project Developer
Author/Editor

A CONCEPTUAL SCHEME FOR MARINE AND COASTAL ENVIRONMENT STUDIES

BY MAURA BEENS TYRRELL AND ROBERT W. STEGNER

1. AN ABUNDANCE OF WATER MAKES THE EARTH UNIQUE IN OUR SOLAR SYSTEM.

- 1.1 Water has a unique combination of chemical and physical properties.
  - 1.11 The chemical and physical behavior of water results in part from the geometry of the water molecule.
  - 1.12 Within the range of temperatures encountered on earth, water exists in three states: solid, liquid, and gas.
  - 1.13 Water exchanges large amounts of heat as it changes in state.
- 1.2 Water in the environment contains a variety of substances in suspension and in solution.
  - 1.21 Water is a very effective solvent.
  - 1.22 Dissolved and suspended substances affect the properties of water.
  - 1.23 Water in nature usually contains gases, organic compounds and mineral salts.
  - 1.24 Many elements dissolved in water are recycled through biological, geological, and chemical systems.

2. AQUATIC ENVIRONMENTS INTERACT WITH THE EARTH AND ITS ATMOSPHERE.

- 2.1 Most of the earth's water is in the oceans.
  - 2.11 Oceans formed early in the history of the earth.
  - 2.12 The earth's surface water is constantly recycled through the oceans.
- 2.2 The ocean waters are influenced by the earth's rotation, revolution, and position in the solar system.
  - 2.21 Ocean current patterns are affected by the absorption of solar energy.
  - 2.22 Ocean current patterns are affected by the earth's rotation.
  - 2.23 Tides result from gravitational forces of the earth, the moon, and the sun.
- 2.3 Energy is transferred wherever bodies of water meet the land or atmosphere.
  - 2.31 Atmospheric movements generate waves, surface currents, and coastal winds.
  - 2.32 Moving water shapes land forms.
  - 2.33 Subsurface topography is constantly changing.
  - 2.34 Land and sea floor movements generate waves.
  - 2.35 The aquatic environment helps to stabilize the earth's climate.

2.4 Materials carried from land masses influence the physical and chemical features of rivers, lakes and coastal zones.
2.41 Water, ice and wind carry minerals, nutrients, sediments and fresh water into rivers, lakes and coastal zones.
2.42 Fresh water from the land dilutes the coastal water.

3. AQUATIC ORGANISMS INTERACT IN COMPLEX ECOSYSTEMS.

3.1 Life probably originated in the marine environment.
3.11 Water facilitated the chemical evolution of organic compounds and coacervates.
3.12 Chemical evolution resulted in heterotrophic systems.
3.13 Autotrophs evolved from heterotrophs.
3.14 Aquatic environments have supported the evolution of a diversity of species.
3.2 Aquatic organisms are adapted to their environments in different ways.
3.21 Aquatic organisms are adapted developmentally, structurally, functionally, and behaviorally to their environments.
3.22 Organisms in aquatic communities interact in balance with their environment and with one another.
3.23 Populations of aquatic organisms are unevenly distributed.
3.3 Aquatic ecosystems depend on a constant flow of energy and the recycling of materials.
3.31 Energy for the maintenance of aquatic ecosystems comes from the sun.
3.32 Aquatic plants convert solar energy to food energy.
3.33 Aquatic organisms transfer energy and materials through food webs.
3.34 Aquatic bacteria reduce organic materials to simpler forms.

3.4 The stability of aquatic ecosystems tends to be directly proportional to the diversity of their populations and the complexity of relationships among them.

4. PEOPLE ARE PART OF AQUATIC ECOSYSTEMS.

4.11 Aquatic environments have affected the course of history and the development of human cultures.

4.11 Oceans, lakes, and rivers have served as routes for the dispersal of human populations and cultures and for commericial transport.
4.12 Proximity to aquatic environments and the availability of aquatic resources have influenced the cultures of many societies.
4.2 People's activities may alter the aquatic ecosystem.
4.21 People collect and culture aquatic resources.
4.22 Exploitation of aquatic environments can cause depletion of many marine and freshwater species and the degradation of habitats.
4.23 People are changing aquatic ecosystems by adding pollutants to land, to air and to water.
4.3 Existing technology is capable of maintaining the health and usefulness of aquatic ecosystems.
4.31 The maintenance of the health and usefulness of aquatic environments depends on value judgments and ethical considerations.
4.32 Regional and international agreements will be essential for the conservation of aquatic resources.

MARINE AQUARIA IN THE CLASSROOM

From kindergarten to graduate school, the marine aquarium arouses interest and enthusiasm. Traditionally, marine aquaria have been very expensive and difficult to operate. Recent technological improvements have reduced the cost and labor involved in maintaining a marine aquarium. Teachers should give every consideration to the establishment of a marine aquarium in the classroom.

Before embarking on a marine aquarium project, some basic questions need to be resolved. These include: How much can I afford (do I want) to spend in time? in effort? A very simple set-up to keep hermit crabs can be had for a few dollars, while an elaborate temperature-controlled aquarium can cost several thousand dollars.

Regardless of the type of aquarium chosen, some facts pertain to all:

1. Aquarium tank -	use only tanks made from all glass, plastic, epoxy-coated wood, or fiberglass. No metal edges. While a 10 gallon aquarium may be used in some cases, 20 gallon size is the preferred minimum.
2. Sub-gravel filter -	a good sub-gravel filter should be employed to help control biological wastes.
3. Air pump -	you can seldom have too much air. Get a pump with a capacity high enough to effectively run the sub-gravel filtration system.
4. Gravel filtrant -	use dolomite, crushed coral rock, or crushed oyster shell. Builders' gravel has iron and similar materials which will harm or kill marine organisms.
5. Thermometer/Hydrometer -	tools useful in determining the salinity and temperature of the water.
6. Seawater -	synthetic sea salts may be used to make salt water solutions if you are more than a day's drive from natural seawater.
7. Food -	depends upon the type of organism. Use only high quality foods and remove uneaten food from aquarium.

If you buy a marine aquarium kit, instructions for set-up will be included. Otherwise, a few hints are given below:

1. Talk to people who have had marine aquaria. (e.g., other teachers, pet shops, etc.) Their assistance can be invaluable.

2. Place the aquarium in desired location, away from direct sunlight, but near an electrical outlet.

3. Install sub-gravel filter.

4. Wash gravel in tap water. Spread evenly over the filter.

5. Fill tank with correct amount of water needed to make sea salt solution (follow directions of manufacturer), or fill to 1 or 2 inches from top with natural sea water if available.

6. Run filtration system for 24 hours to mix solution.

7. Shut off filter. Check specific gravity by floating hydrometer and reading it at the water-line: it should read between 1.021 and 1.023 when the water temperature is 68-77°F (20-25°C). If necessary, adjust by adding tap water to lower reading.

8. Run filter for 14 days. Some aquarists recommend placing one or two hardy specimens in the tank for this period. If available, hermit crabs or the like should be added to help condition the water.

9. Add specimens to tank. If you order the animals from a biological supply house, they will come with directions. Otherwise, open each plastic bag of specimens in subdued light and float it on top of the water in the aquarium for 15 to 30 minutes. In this period trickle water from the tank into the bags to slowly equalize temperature and salinity. This is the crucial step. Now add animals to tank, one at a time. (If animals act nervous or contract, stop operation until they have adjusted.)

10. The specimens will live several months without being fed, but to keep them healthy, adopt a simple, regular feeding program. Feed carnivorous invertebrates (sea anemones, crabs, horseshoe crabs, starfish, etc.) once a week: they take small minnows, shrimp, earthworms, bits of lean beef. Filter-feeders (barnacles, hydroids, sea cucumbers, clams, etc.) eat Daphnia, brine shrimp, algae, protozoa, or dried fish foods. Herbivorous species (sea hares, sea urchins, turban snails, etc.) may be fed lettuce or spinach. Avoid water pollution --- remove all uneaten food.

Not all plants and animals are suitable for marine aquaria. Sea anemones, chitons, snails, crabs, shrimp, horseshoe crabs, hermit crabs, starfish, and brittle stars make good specimens. Avoid the burrowing forms. Sponges, jellyfish, corals, marine worms, and sand dollars should be avoided, since they may die unseen and foul the water. Cautious observation of fish and plants will determine which species will survive well in your situation. It is important to watch the organisms in your aquarium and remove any deceased members of the community immediately. Further information about suitable organisms can be found in the references cited below.

Once the system is operating, care is easy. Each day, a person familiar with the aquarium should check filters and specimens. Dead animals must be removed at once. Add tapwater as often as necessary to keep water at level marked. Do not add salt water, since this will increase the salinity.

Though sea-salts don't disintegrate, specimens will stay healthier with partial water changes at regular intervals. Suggestion: once a month, add a few gallons of new seawater solution after siphoning off the same amount from the tank.

For algae control, scrape tank walls every two weeks.

The above suggestions apply to all marine aquaria. If you live in a Northern latitude and want to keep local cold water species, you will need a refrigeration unit of some description. Instructions for home-made units can be found in reference books on marine aquaria. Ready-made refrigerated aquaria are available and expensive.

If, after reading the above, you are discouraged, take heart. Hundreds of teachers are operating successful in-class marine aquaria. The technical problems can be overcome. If you feel that it is unquestionably "out of your league" and you cannot obtain help from another source, do not completely forsake the idea. A simple aquarium for hermit crabs can be set up for a very few dollars. Solicit donations from students -- all glass aquaria are plentiful. Go to a pet shop and buy a hermit crab or two and get instructions on how to keep them alive. It can be fun! At the very least, set up a freshwater aquarium with goldfish or tropical fish so that you can use a living example when you talk about aquatic organisms. Here is a real opportunity to use all that creativity that got you into teaching in the first place. Good luck!

RECOMMENDED READING

James, Daniel E.	*Carolina Marine Aquaria*, Carolina Biological Supply Co., 2700 York Road, Burlington, North Carolina 27215, 1974. This booklet is available from the above address and offers valuable assistance as well as information for single organisms or complete kits. 24 pages.
King, John M. and Spotte, Stephen	*Marine Aquariums in the Research Laboratory*, Aquarium Systems Inc., 33208 Lakeland Blvd., Eastlake, Ohio 44094, 1974. Describes tank set up and maintenance, as well as offering experiments which can be performed using marine aquaria. Also advertises Instant Ocean products. 39 pages.
Straughan, Robert P.L.	*The Salt-Water Aquarium in the Home*, 2nd edition, A.S. Barnes and Co., New York, 1970. A comprehensive reference. 360 pages.

BIBLIOGRAPHY OF SELECTED BOOKS ABOUT THE MARINE ENVIRONMENT

The ocean by its very nature lends itself to a multidisciplinary teaching approach. The following list of books related to the marine environment is provided to help you arouse in your students an awareness of the world around them and an awareness of their relationship with and their responsiblity toward their environment. The books were selected to be appropriate for young readers thirteen and older. The list is not intended to be comprehensive, but it does include enough variety to begin a real reading affair with materials dealing with the sea.

The books listed were selected because of their presence on two or more bibliographies of works dealing with the sea. For a more comprehensive, though largely unannotated, list of books available, consult:

> Project COAST. A List of Books on the Marine Environment for Children and Young People. University of Delaware, College of Education; Newark, 19711. 1978. 62 pages.

Amos, William H. The Life of the Seashore. McGraw-Hill, Inc. 1966.

From the publishers of "Our Living World of Nature" series, this colorful marine work is a good introduction for a trip to the coast.

Barbour, John A. In the Wake of the Whale. Crowell Collier Press. 1969.

A readable book that describes the life history of the different whales. It also contains a very good discussion of whaling practices and how they have affected whale populations.

Bascom, Willard N. Waves and Beaches: The Dynamics of the Ocean Surface. Doubleday Anchor Books. 1964.

A straight-forward presentation of waves, tides and how the sea interacts with the land.

Benchley, Nathaniel. Beyond the Mists. Harper and Row Publishers. 1975.

Based on the Norse sagas, this is a fascinating account of the violent and hazardous world of Viking raiders and explorers.

Berrill, N.J. The Life of the Ocean. McGraw-Hill, Inc. 1966.

One of the "Our Living World of Nature" series. Also a colorful introduction to the oceans.

Bonham, Frank. Deepwater Challenge. Thomas Y. Crowell Co. 1963.

A young boy, determined to become the family breadwinner, learns that trying to outwit the sea is a tough and dangerous job.

Brown, Joseph E. Sea's Harvest. Dodd, Mead & Co. 1975.

The story of modern aquaculture with a summary look at the future.

Carson, Rachel L. The Sea Around Us. Oxford University Press. 1961.

Excellent general review of descriptive oceanography, somewhat dated, but a beautifully written book.

Clarke, A.C. The Challenge of the Sea. Holt, Rinehart & Winston, Inc. 1960.

A scholarly discussion of man's exploration and exploitation of the sea's resources with a look at some future possibilities.

Cowen, Roger C. Frontiers of the Sea (revised edition). Doubleday & Co. 1969.

An oceanographic best seller. This revised edition updates the original book to include oceanographic events that took place during the decade of the sixties. The book is written in a lucid and authoritative prose.

Cromie, William J. Exploring the Secrets of the Sea. Prentice-Hall, Inc. 1967.

An enjoyable introduction for the young reader.

Defant, Albert. Ebb and Flow: The Tides of Earth, Air and Water. University of Michigan Press. 1958.

A good introduction to tides.

Engel, Leonard and the editors of Time, Inc. The Sea. Time-Life, Inc. 1969.

An engaging and attractive presentation of the marine environment. The illustrations are magnificent and text is substantial. The photographs are excellent and the drawings are very well done.

Fairbridge, Rhodes W. The Encyclopedia of Oceanography. Reinhold. 1966.

A collection of information which previously was found only in text books and reference works.

Gross, M. Grant. Oceanography. Charles E. Merrill Publishing Company. 1967.

A well done overview of the marine sciences.

Gullion, Edmund A., editor. Uses of the Seas. Prentice Hall International, Inc. 1968.

A background book for American Assemblies on Uses of the Seas discussion groups, but the general reader will find it valuable especially in the areas of national and international law and organization in the sea.

Hardy, Sir Allister. The Open Sea: Its Natural History. Houghton Mifflin Co. 1965.

To quote one reviewer, "This is one of the great books about the sea of our generation. The best introduction to marine biology for the layman that we have."

Hemingway, Ernest. The Old Man and the Sea. Charles Scribner's Sons. 1952.

Classic that explores the mysteries of the sea, the meeting of youth and old age, the glories of a solitary purposeful life, the battle for recognition, and the struggle of the human spirit for survival.

Heyerdahl, Thor. Kon-Tiki. Rand McNally & Co. 1950.

Classic research in the field of cultural migration/transmission. Adventure and history in a text about the influence of the sea on cultural development and world history.

Idyll, C.P. Abyss. Thomas Y. Crowell Co. 1964.

A most interesting treatment of the deep oceans and the creatures that dwell therein.

Idyll, C.P., editor. Exploring the Ocean World. Thomas Y. Crowell Co. 1969.

A history of geographic, oceanographic, and even archeologic studies of the oceans from ancient times to the present; geared to an interested, non-technical audience.

King, Cuchlaine A.M. An Introduction to Oceanography. McGraw Hill Book Co. 1965.

Intended for those without a background in physics, mathematics and biology.

Linklater, E. The Voyage of the Challenger. Doubleday. 1972.

Well written and beautifully illustrated account of the first global oceanographic expedition. An intensely interesting story for those interested in marine science or history.

Lord, Walter. A Night to Remember. Holt, Rinehart & Winston, Inc. 1955. and Bantam Books, Inc. 1955.

Suspenseful story of the Titanic: gallantry, bravery, foolishness, cowardice.

Loti, Pierre (Pseudonym for Biaud, Julien). An Iceland Fisherman. Reprinted by J.M. Dent & Sons. 1961.

Tells of the love of a group of people for the sea, and how the sea influences every aspect of their lives: the superstitions, the faith, and the beauty.

Marx, Wesley. The Frail Ocean. Ballantine Books, Inc. 1967.

A discussion of pollution and related matters.

McCoy, J.J. A Sea of Troubles. Seabury Press. 1975.

Examines the present-day threats to the vast resources of the world's oceans and the political and economic conflicts involved in trying to save the sea from irreversible damage.

Miller, Robert C. The Sea. Random House. 1966.

A well illustrated, general reference of marine topics that treats most aspects of marine science.

Norton, Andre. Sea Siege. Harcourt Brace Jovanovich, Inc. 1957.

Shows effects of an atomic blast on an isolated island. Presents ecological interrelationships and discusses changes in environment and lifestyles.

Ommanney, F.D. The Fishes. Time, Inc. Life Nature Series. 1963.

Like other books in the series, this is well illustrated.

Piccard, Jacques, and Dietz, Robert S. Seven Miles Down, The Story of the Bathyscaphe Trieste. G.P. Putnam's Sons. 1961.

An account of the bathyscaphe and its deepest dive. Good for engendering student interest in oceanography.

Polmar, Norman. Death of the Thresher. Chilton Book Co. 1964.

Documentary account of the loss of a U.S. atomic submarine with its one hundred twenty-nine crewmen.

Rabling, Howard. The Story of the Pacific: Explorers of the Earth's Mightiest Ocean. W.W. Norton & Co. 1965.

An absorbing, well written history of the Pacific from Magellan to the mid-nineteenth century.

Reish, Donald J., editor. Biology of the Oceans. Dickenson Publishing Co., Inc. 1969.

An anthology of biological oceanographic articles giving insight into methods and types of research done by the biologist in the sea.

Ricciuti, Edward R. Killers of the Seas. Walker & Co. 1975.

Fascinating yarns and useful facts about dangerous creatures found in the waters of the world.

Ricketts, Edward F. and Calvin, Jack, rev. by Joel W. Hedgpeth. Between Pacific Tides. 4th edition. Stanford University Press. 1968.

The standard work for West Coast people who are interested in life along the shore.

Scheffer, Victor B. Year of the Whale. Charles Scribner's Sons. 1969.

An excellent dramatization of whale biology.

Smith, Harvey Garrett. The Marlinspike Sailor. John DeGraff, Inc. 1975.

Crafts and projects based on traditional skills of the sea: knots, splices, whippings, rope ladders, lanyards, fenders, mats, grommets, decorations for chests, bags and fittings.

Southward, A.J. Life on the Sea-Shore. Harvard University Press. 1965.

Provides excellent examples of how to study various problems of biology on the sea shore. Recommended for those interested in designing constructive field trip exercises.

Steinbeck, John. The Pearl. Viking Press. 1947.

A poor, superstitious Mexican finds a priceless pearl. With it he wants to buy respect and health for his family. His wife, thinking the pearl is evil, wants him to get rid of it. Many conflicts develop as others try to steal his pearl.

Thorson, Gunnar. Life in the Sea. McGraw Hill Book Co. 1971.

Excellent discussion of marine biology.

Warner, William W. Beautiful Swimmers. Penguin Books. 1977.

A natural history of the blue crab is combined into a study of Chesapeake Bay and of the water men who make a living in the crab's pursuit.

Williamson, W.M., editor. The Eternal Sea: An Anthology of Sea Poetry. Books for Libraries, Inc. 1946.

Twenty-one chapters of poetry arranged by titles such as "The Call of the Sea," "Homeward Bound; Making Port," "Fishermen..."

Yasso, Warren E. Oceanography. Charles E. Merrill Publishing Co. 1967.

Used in many high schools as a background text.

Yonge, C.M. The Seashore. Collins. 1949.

Although written about British shores, this is a standard little volume which should be on the shelf of all who visit the edge of the sea.

HISTORICAL PERSPECTIVES

TEACHER BACKGROUND - Charles Darwin - Three Level Guide

The history of oceanography is full of controversy. The voyage of the Beagle brought the attention of the scientific community to the sea and precipitated a series of exploration cruises that would continue to this day. It is fitting to begin a study of the world oceans with a glance at the past. This activity and "The Voyage of the Challenger - Three Level Guide" provide your students with a slice of oceanographic history. The goal is to put today's knowledge and activities in perspective. The activities are designed to set the mood for the lessons to follow. Emphasize our increase in knowledge since the sailing of the Beagle, while noting how far we have to go to accomplish an understanding of the seas.

The article is difficult reading for many students. This article seems to typify a problem seen in teaching today: we can have articles that cover the material but are too difficult to read, or we can have articles that can be read but do not cover the material. The three level guide presented here is one way to solve this seeming dilemma. Three level guides are based on what seems to be the general agreement that comprehension can take place at different levels of cognition. Harold L. Herber has called these levels: 1) literal, 2) interpretive and 3) applied. With the exception of the literal level, each level requires the product of the previous level or levels in order to function.

The literal level of comprehension produces knowledge of what the author said. We all recognize that it is quite possible to identify and even repeat what an author has said without understanding what he or she meant by the statements. The interpretive level of comprehension depends upon the reading performed at the literal level but carries the process a step further. At this level the reader derives meaning from what the author has said. The meaning is determined by the way the reader perceives the intratext relationships. The applied level of comprehension takes the product of the literal (what the author has said) and the interpretive (what the author meant by what he or she said) and applies it in some practical or theoretical exercise. At this level, the reader is using his past experiences and knowledge to produce new ideas which extend beyond those immediately identifiable in the reading selection. It must be borne in mind that the level at which a person reads does not reflect upon his or her intelligence and that the level can change as the material changes. The most advanced engineers and scientists often read at the literal level if they cross into other disciplines. When we read materials from an area with which we have little familiarity, our level of comprehension goes down. Your students are no exception to this observation. The three level guide is a device used to improve a person's comprehension by focusing on important concepts at each of the three levels. The three level guide can be used with any material and is readily constructed. For aid in this regard, please see:

> Teaching Reading in the Content Areas. 1970. Harold L. Herber. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. 296 pages.

Duplicate the pages of the three level guide. One set is recommended per student. Spend a few minutes describing what is expected of the student. Suggest that the students read the statements in the three level guide before they read the article. In this way, the statements serve as a preview and your students will be looking for and expecting to see certain concepts. You may elect to have your students compare their answers by meeting in small groups. The process of resolving differences in opinion can be very instructive.

Upon completion of the reading and the three level guide, discuss the guide by reference to the article. It is sometimes helpful to have your students note the page number and paragraph number where they find evidence supporting or refuting the statements in the guide. You can require your students to provide this information or you can offer extra credit for those that include it. Choose the technique that most appeals to you and best fits the needs and skills of your class.

If you have not already done so, now is the time to become familiar with the organization of this guide. Each major division (for example, "Ocean Floor") has an introductory reading which sets the background for that section. The reading includes text questions for your students to answer as they read. The major divisions also include student activities and laboratory exercises. Each activity and exercise has a separate "Teacher Background" section. The readings and activities for each section increase in difficulty as you progress within the section. The differences in the difficulty of the articles will allow you to provide materials to fulfill the needs of the variety of students typically found within a single class. The range of materials provided can help you to individualize your instruction. There are several ways to teach the materials included in this guide. Two possible approaches are included here by way of suggestion. Each reading or activity can be presented, in the order listed in the index, to the whole class simultaneously. You can decide which of the advanced activities to include by your knowledge of the class or by stopping when the activity just completed was obviously too difficult for the majority of your students. An alternative approach involves the preparation of a file of class sets of the student readings and activities presented. Each student is given a checklist (see example) of the activities and readings in the file. The students may work on any activity at any time. Prior to employing this approach, you will need to advise your class of their responsibilities and of the grading procedure to be followed. For example, you may wish to have a list of the assignments which must be satisfactorily completed to earn a C grade, a B grade or an A grade. A deadline for completion of the unit must be posted. The materials required for the activities and laboratory exercises must be accessible to the students. This approach requires more advance planning and advanced duplication of the materials than the first approach mentioned.

It has the advantage of placing an increased amount of responsiblity for completion upon the student. Other approaches are also possible. Whichever approach you select, it is important that you generate enthusiasm for study about the marine environment before you begin and during the course of study.

KEY

The correct answers are checked on the three level guide found on the following pages.

CHARLES DARWIN - Three Level Guide

Level I. Directions: Read the statements carefully. Then as you read the selection, refer back to the statements in the guide and check those that you believe say what the author actually said or paraphrased in the selection. Indicate the page, paragraph and sentence on the statements checked for later reference. Also, be ready to explain what is inaccurate about the statements that you do not check.

The Intelluctual Setting

____ 1. The notion of a continuity of events, of one animal changing by degrees into another was accepted as common sense before Darwin.

✓___ 2. Darwin is accorded so important a place in biological history due to his supreme act of creative synthesis.

The Voyage

✓___ 1. Darwin sought to relate bones and fossils from past animals to animals of the present.

✓___ 2. Darwin observed that characteristics of vegetation and animal life tend to vary by slow degree.

____ 3. Darwin's travels do not provide him with any information concerning the changing character of the earth or its age.

The Invalid and the Book

____ 1. Upon his return, Darwin became a celebrity and gave many public lectures about the voyage.

✓___ 2. Darwin's seclusion resulted in the organization of an enormous battery of facts which documented the theory of evolution as it had never been documented before.

✓___ 3. From his studies, Darwin reached the conclusion that since variation in individual characteristics existed among the members of any species, selection of some individuals and elimination of others must be the key to organic changes.

✓___ 4. Thomas Malthus' work on the human population provided Darwin with the idea that the struggle for existence under changing environmental conditions was what induced alterations in the physical structure of organisms.

Procrastination

✓___ 1. Darwin planned to reveal his theory of evolution in a monumental book.

✓ 2. Other authors published books dealing with creation.

✓ 3. Alfred Russel Wallace sent Darwin a copy of his article explaining his theory of evolution.

____4. Darwin gave up his idea and did not publish his theory.

Publication

____1. To convince the public, Darwin wrote a second volume explaining all theat could not be made clear in the abstract.

✓ 2. The science world agreed with Huxley who said, "How extremely stupid not to have thought of that!"

✓ 3. Darwin proved the reality of evolutionary change beyond any reasonable doubt, and demonstrated, in natural selection, a principle capable of wide, if not universal, application.

A Small Place for Man

____1. In the "Origin of the Species," Darwin went into great depth discussing the evolution of man.

✓ 2. In "The Descent of Man," Darwin failed to distinguish consistently between biological inheritance and cultural influences upon the behavior and evolution of human beings.

____3. Man was not Darwin's best subject.

The Islands

✓ 1. Darwin needed evidence for the continuity of life. He found it in the oceanic islands.

✓ 2. The island worlds that gave the information for Darwin's theory are disappearing, many without ever having been seriously investigated.

Level II. Directions: The statement below may or may not be true. Check each statement you believe is a generalization the author himself draws based on the information he gives in the selection. Indicate the page, paragraph and sentence on the statements checked for later reference.

The Intelluctual Setting

✓ 1. Like many scientific discoveries, other investigators had set the stage for Darwin's theories.

____2. Darwin's theory was bound to meet with world-wide approval because of the intellectual climate of the time.

The Voyage

✓ 1. Darwin is a careful observer.

✓ 2. Darwin was not aware at first of the extreme importance of his observations in the Galapagos.

The Invalid and the Book

____ 1. During his withdrawal from society, Darwin was able to create his theory based solely on his own work.

✓ 2. Darwin's importance comes not from the fact that he discovered all of the elements necessary to form his theory, but rather from the fact that he recognized variation, inheritance of variation, selective breeding and the struggle for existence as related parts of one whole.

Procrastination

✓ 1. Darwin spent much time formulating theories about various phenomena.

✓ 2. Darwin was afraid to publish his book.

✓ 3. Wallace's letter forced Darwin to act.

Publication

____ 1. Darwin's theories apply to all animals with the exception of man.

✓ 2. Scientific theories should clarify and simplify our knowledge.

A Small Place for Man

____ 1. Even Darwin's fellow scientists thought he was a bit crazy.

✓ 2. Darwin preferred to have his human subjects dead.

The Islands

____ 1. The destruction of island habitats is of little significance to man.

✓ 2. Darwin looked on the unknown as a challenge.

Level III: Directions: Read each statement below, relating the details and author's interpretations drawn from the selection to ideas and experiences you've had in reference to this topic. In column A, check the statements which Darwin would have agreed with. In column B, check the statements you agree with.

A B

____ ____1. All plants and animals were created in the same form in which we see them today.

__✓__ ____2. The principles of natural selection and evolutionary change can help man to "create" new breeds of livestock and other kinds of animals and plants.

____ ____3. The animals and plants we see about us today will remain unchanged for the rest of time.

____ ____4. Man is the one animal that has not changed and will not change in the future.

__✓__ ____5. Scientific investigation provides facts that will lead every investigator to the same conclusions.

CHARLES DARWIN

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KEY WORDS

accorded

characteristics

evolution

fossil

inheritance

paraphrased

phenomena

scientific investigation

seclusion

selection

significance

variation

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TEACHER BACKGROUND - The Voyage of the Challenger - Three Level Guide

Early explorers of the ocean depths postulated a lifeless zone at the bottom of the sea. Plants and animals were thought to occur in definite depth zones. The number of organisms was believed to decrease with depth until, at about three hundred fathoms, life ceased. The British Admiralty provided the HMS Challenger to prove or disprove the hypopothesis, while conducting a general ocean survey. The article, "The Voyage of the Challenger," gives an interesting account of this most famous of all oceanographic expeditions.

Duplicate the three level guide. One is recommended per student. This activity is best accomplished individually. The educational rationale for the three level guide is found in the Teacher Background section for "Charles Darwin - Three Level Guide." Please read the rationale if you have not used the three level guide approach before. Spend a few minutes describing what is expected of the student. Suggest that the student read the statements in the three level guide before reading the article. In this way, the statements serve as a preview and your students will be looking for and expecting to see certain concepts. Upon completion of the reading and the three level guide, discuss the guide by reference to the article. It is sometimes helpful to have your students note the page number and paragraph number where they find evidence supporting or refuting the statements in the guide. You can require your students to provide this information or you can offer extra credit for those who include it. Choose the technique that most appeals to you and best fits the needs and skills of your class.

KEY

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KEY WORDS

bathybius

evolutionary

interpretations

paraphrased

sounding the depths

2

THE VOYAGE OF THE *CHALLENGER*

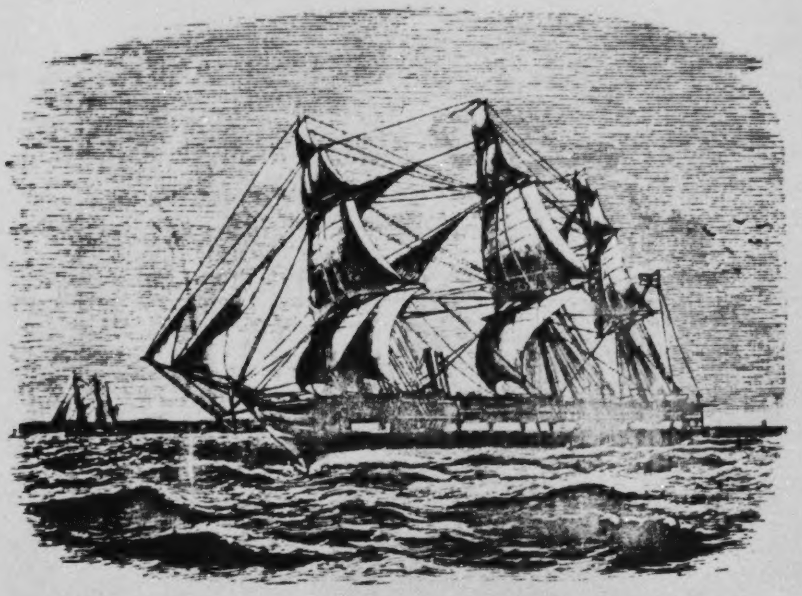
HERBERT S. BAILEY, Jr.
May 1953

JUST 77 years ago this month a spar-decked little ship of 2,300 tons sailed into the harbor of Spithead, England. She was home from a voyage of three and a half years and 68,890 miles over the seven seas. Her expedition had been a bold attack upon the unknown in the tradition of the great sea explorations of the 15th and 16th centuries. The unknown she had explored was the sea bottom. When she had left England, the ocean deeps were an almost unfathomed mystery. When she returned, she had sounded the depths of every ocean except the Arctic and laid the foundation for the modern science of oceanography.

The ship was called the *Challenger*. Her name and voyage are already covered with the dust of time, but her story is worth reviving today, when far more handsomely outfitted expeditions are once more exploring the sea deeps. They are filling in details and retouching parts of a picture which in its broad outlines has remained essentially unchanged since that pioneering voyage. It was the *Challenger*, rigged with crude but ingenious sounding equipment, that charted what is still our basic map of the world under the oceans.

Before the *Challenger*, only a few isolated soundings had been taken in the deep seas. Magellan is believed to have made the first. During his voyage around the globe in 1521 he lowered hand lines to a depth of perhaps 200 fathoms (1,200 feet) in the Pacific; failing to reach bottom, he concluded that he was over the deepest part of the ocean. (Actually the water where he took his soundings is 12,000 feet deep, far from the deepest bottom in the Pacific.) After Magellan no deep-sea soundings were taken for about 300 years. In the 19th century a few sea captains and layers of telegraph cables began to plumb deep waters, some of them getting their lines down as deep as two miles or more.

One of the first men to take a scientific interest in the ocean depths was Edward Forbes, professor of natural philosophy at the University of Edinburgh. He did some dredging in the Aegean Sea, studying the distribution of flora and fauna and their relation to depths, temperatures and other factors. Forbes never dredged deeper than about 1,200 feet, and he acquired some curious notions, including a belief that nothing lived in the sea below 1,500 feet. But his pioneering work led the way for the *Challenger* expedition.



H.M.S.* Challenger, *as depicted in the official* Challenger *report

THE MAN WHO organized the expedition was Charles Wyville Thomson, Forbes's successor as professor of natural philosophy at Edinburgh. Thomson first made some summer dredging cruises in ships borrowed from the British Admiralty, and the results were so interesting that they prompted Thomson and the Royal Society to approach the Admiralty with a much more ambitious project. They asked for a vessel that could carry out an investigation of the "conditions of the Deep Sea throughout all the Great Oceanic Basins." The naval authorities, now fully awake to the importance of oceanic research, provided H.M.S. *Challenger*, a corvette fitted with auxiliary steam power in addition to her sails. A naval crew under Captain George S. Nares was assigned to the mission, and Thomson selected a staff of scientists and other civilians to assist him.

They proceeded to adapt or improvise the necessary scientific equipment and to fit out laboratories on the ship. To make room for their gear they removed all but two of the warship's 18 guns. Their equipment included instruments for taking soundings, bottom samples and undersea temperatures; winches and a donkey engine; 144 miles of sounding rope and 12.5 miles of sounding wire; sinkers, nets, dredges, a small library, hundreds of miscellaneous scientific instruments and "spirits of wine" for preserving specimens.

The expedition, coming after Charles Darwin's famous voyage in the *Beagle* and in the midst of the great uproar over his new theory of evolution, naturally attracted public attention. Even

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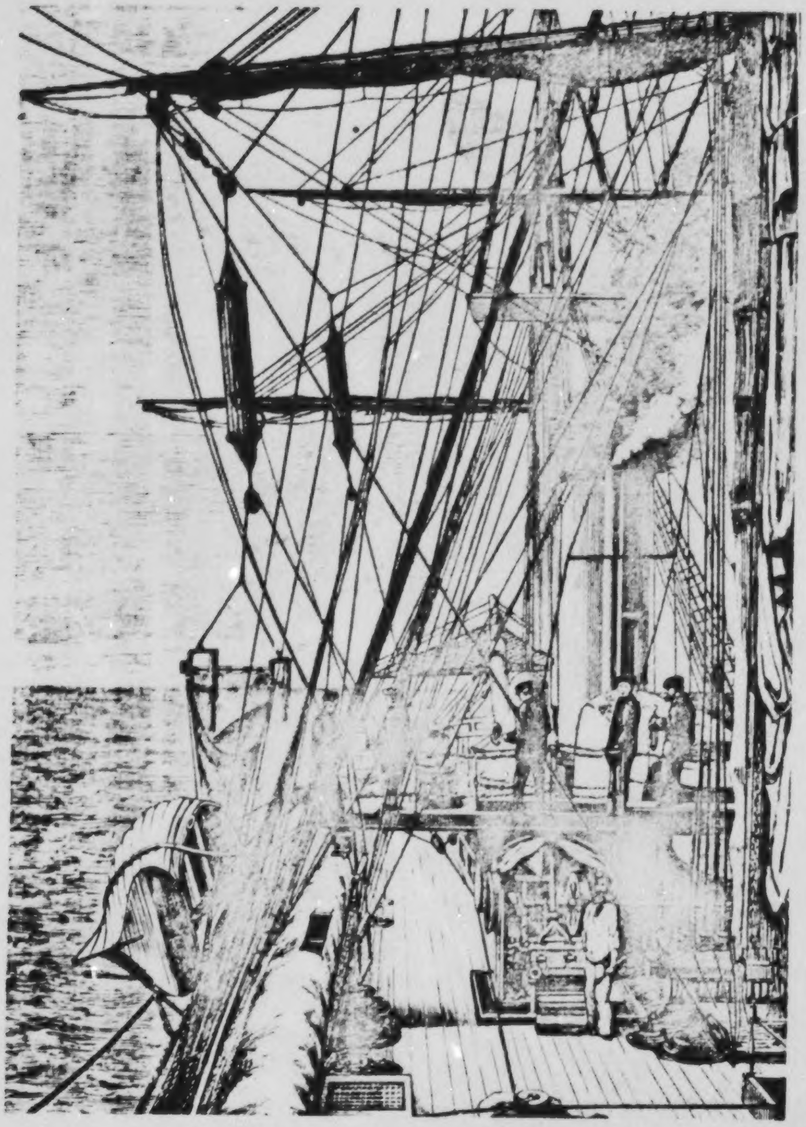


Dredging and sounding apparatus on the deck of the Challenger

Punch gave the *Challenger* a send-off:

> *Her task's to sound Ocean, smooth*
> *humours or rough in,*
> *To examine old Nep's deep-sea*
> *bed. . . .*
> *In a word, all her secrets from Nature to wheedle,*
> *And the great freight of facts*
> *homeward bear.*

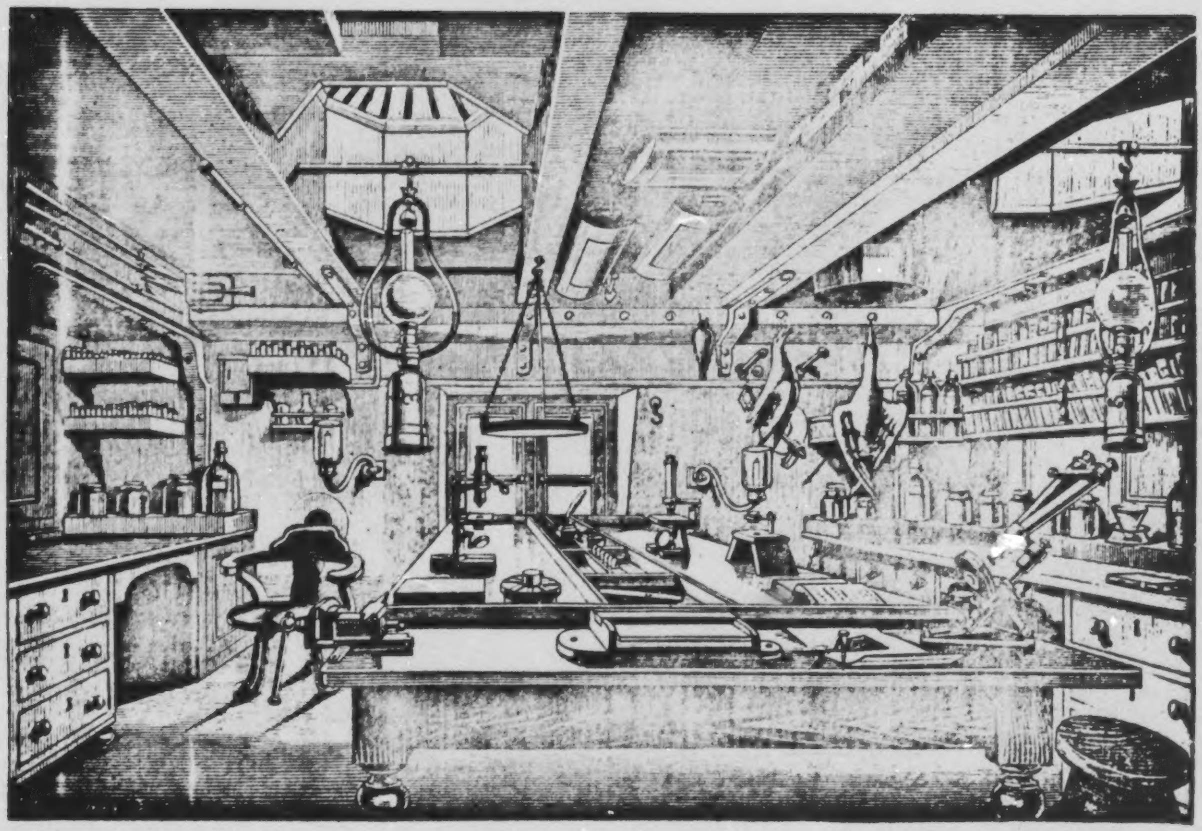
The *Challenger* sailed from Portsmouth on December 21, 1872. She immediately ran into a howling storm at sea. Thomson found this no evil omen, pointing out that the gale "brought all our weak points to light" and increased confidence in the arrangements. His staff spent the first leg of the voyage, as far as Bermuda, in training and practice on their work: sounding, dredging, trawling and making measurements. Holding the ship steady with her steam engines, the civil and naval crews each time took a standard series of observations: the total depth of water, the temperatures at various depths, the atmospheric and meteorological conditions, the direction and rate of the current on the ocean surface and occasionally of the currents at different depths. They also dredged up samples of the bottom, including its plant and animal life, and dipped up samples of the water and of the sea life at various levels. They found they had to make their soundings with the hemp rope, because the wire tended to kink and break. Attached to the line were sinkers, thermometers and water bottles; when the sinkers hit the bottom they were automatically detached. By the time they had finished their voyage, they had made such observations at 360 stations scattered over the 140 million square miles of the ocean floor.

The routine was long and laborious. In really deep water it took more than an hour and a half to reach bottom—and much longer to haul the line back. "Dredging," wrote one of the naval officers, "was our *bête noire*. The romance of deep-water trawling or dredging in the *Challenger*, when repeated several hundred times, was regarded from two points of view: the one was the naval officer's, who had to stand for 10 or 12 hours at a stretch carrying on the work . . . the other was the naturalist's . . . to whom some new worm, coral, or echinoderm is a joy forever, who retires to a comfortable cabin to describe with enthusiasm this new animal, which we, without much enthusiasm, and with much weariness of spirit, to the rumbling tune of the donkey engine only, had dragged up for him from the bottom of the sea."

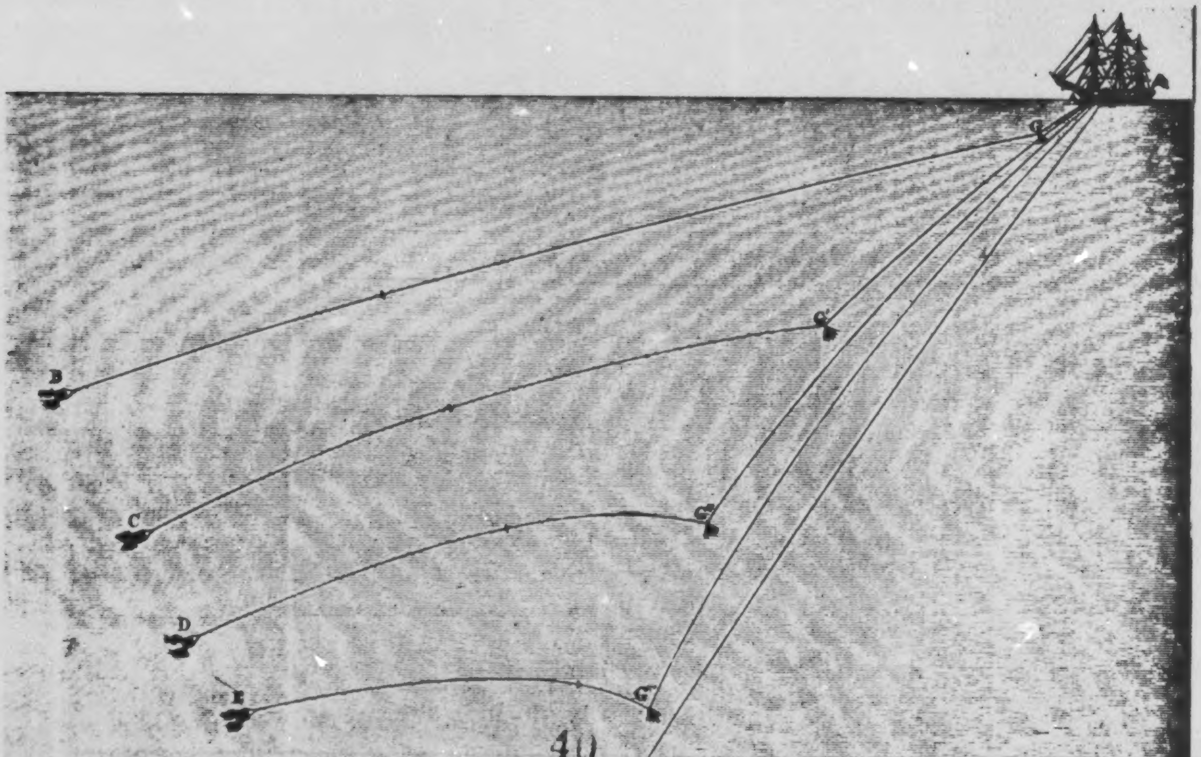
THE TRIP was not, however, all drudgery. There was romance and adventure enough to inspire the officers and scientists, almost to a man, to produce memoirs, logs and other accounts for an eagerly waiting public at the end of the voyage. One of the first diversions occurred in the South Atlantic. Putting in at the tiny colony of Tristan Island, the *Challenger's* crew learned from the inhabitants that two brothers named Stoltenhoff, seeking their fortune at seal-hunting, had marooned themselves nearly two years earlier on aptly named Inaccessible Island. The ship diverted its course to rescue the brothers. They had kept themselves alive on a diet of penguins' eggs and wild pigs, but had had no luck catching seals. The ship also stopped at nearby Nightingale Island, a rookery for hundreds of thousands of penguins, and found it so covered with eggs that the shore party could hardly walk without stepping on them. The penguins defended their nests furiously and pecked one of the ship's dogs to death.

Beyond Cape Horn, on Marion Island, they saw multitudes of white albatross, but, heeding the warning of the Ancient Mariner, they killed none. This was a rare exception, for it was their practice to collect specimens of indigenous flora and fauna wherever they touched land.

Exploring in the southernmost Indian Ocean, the *Challenger* became the first steamship to cross the Antarctic Circle. The scientists were tremendously interested in the icebergs and even fired a cannon at one to break off a chunk. In an unsuccessful attempt to find the "Termination Land" reported by the U. S. explorer Charles Wilkes, the *Challenger* ran into a sudden antarctic storm while traversing a pack of icebergs. With the wind at 42 miles per hour and night coming on, the ship took refuge in the lee of a large berg, holding position close beside it with the steam engine. During an unexpected lull in the wind



The zoological laboratory of the Challenger (above), *and the principle of its deep-sea dredges* (below)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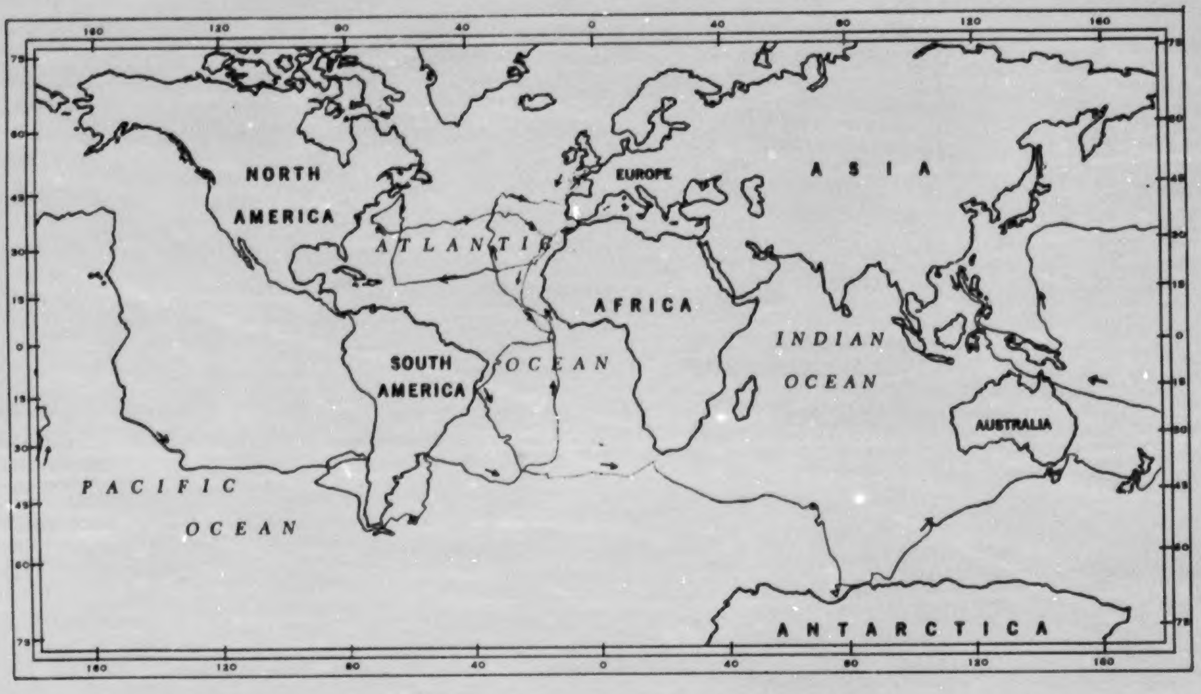


A general outline of the voyage of the Challenger

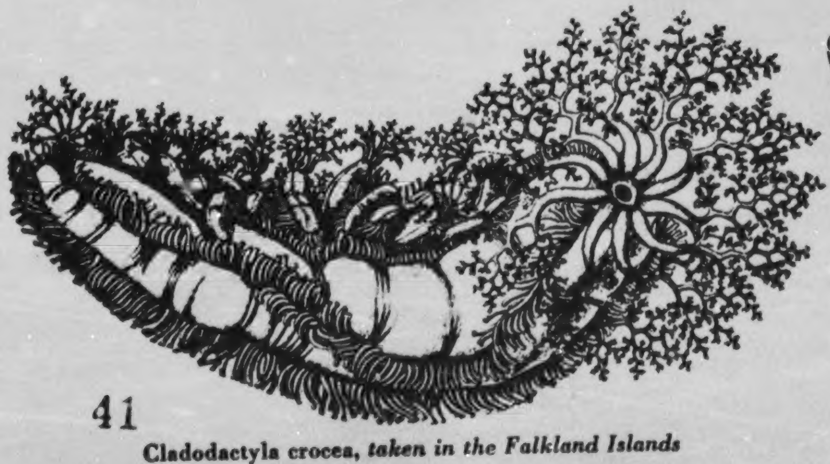
the ship rammed the berg before the engine could be reversed and lost its jib boom and other rigging. The damage was not serious and the rigging was recovered, but the company spent an anxious night steaming back and forth in a dense snowstorm between two large icebergs.

The ship next went on to Australia, New Zealand and the Pacific islands. In the Fijis they interviewed King Thackombau, a converted Christian, who had earlier cut out a prisoner's tongue and eaten it in his sight--before eating the prisoner himself. The ship called at the Philippines, Japan, China and the Admiralties. On March 23, 1875, off the Marianas Islands, the explorers hit their deepest sounding—26,850 feet. This was not very far from the deepest of all time: the record to date is a sounding of 34,440 feet, made in the Mindanao Trench off the Philippines by a U. S. Navy vessel in 1950.

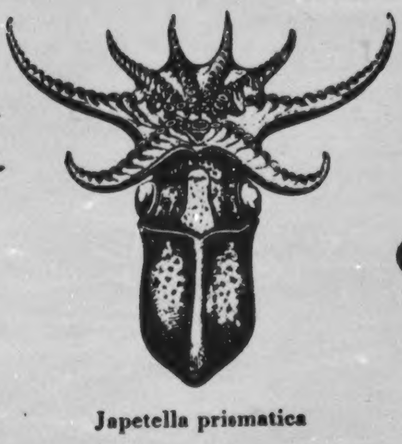
The *Challenger* zigzagged across the Pacific, stopping at the Hawaiian Islands and Tahiti, and then rounded South America through the Strait of Magellan. It swung north through the South and North Atlantic and finally arrived home in England on May 24, 1876.

Of the *Challenger*'s crew of some 240 men, seven died during the trip: two by drowning, one of yellow fever, the others of accidents and miscellaneous causes. Several of the crew jumped ship in Australia. The remainder returned to a joyful welcome—and to the long, hard task of organizing the vast amount of data accumulated on the voyage.

A COMMISSION was set up in Edinburgh to assess the results of the voyage, which were eventually published in an official report of 50 volumes. Two volumes contain a "summary of scientific results"; two a "narrative of the voyage." The other 46 are monographs written by some of the leading scientists of the day, among them T. H. Huxley,



Cladodactyla crocea, ***taken in the Falkland Islands***



Japetella prismatica

Alexander Agassiz, H. N. Moseley and the great German biologist Ernst Haeckel. Most famous of the official reports are Haeckel's monographs on certain sea organisms that had previously been relatively little known. One of the most interesting is on the radiolaria, of which the expedition collected 3,508 new species to add to the 600 then known.

To see the *Challenger*'s scientific results in proper perspective one must remember that the voyage took place at a time when every new discovery was an exciting prize to be fitted into the evolutionary table. The *Challenger* discovered 715 new genera and 4,417 species of living things, thus demonstrating that the oceans were teeming with unknown life waiting to be classified. It proved beyond question that life existed at great depths in the sea. The voyage opened the great descriptive era of oceanography, which was followed by the analytic oceanography of our own century.

The summary volumes were written by Sir John Murray, who became head of the commission after Thomson, exhausted by the voyage, died in 1882. Murray's comments and theories have had an important influence on oceanography. He strongly put forward the view, for example, that at equivalent latitudes both the Arctic and the Antarctic have similar marine organisms, and that these are not to be found in the more temperate zones. This "bipolarity" theory has now been discarded, but for a time it stimulated much investigation. Murray also asserted that, contrary to what had been hoped and expected, the deep sea did not yield a widespread fauna of great antiquity, though some very ancient species were found. He believed that under about 600 feet below sea level the bottom deposits and fauna become more uniform with increasing depth until a point is reached at which conditions are almost the same in all parts of the world. He added, "When once animals have accommodated themselves to deep-sea conditions there are few barriers to further vertical or horizontal migration." Such suggestions, based on the *Challenger's* observations, gave direction to further investigation.

The expedition washed out of existence a form of living matter that had been "observed" by Huxley and described by Haeckel. On the basis of preserved specimens dredged during earlier expeditions, Haeckel had decided that the entire ocean floor, or at least a major part of it, was covered with a thin layer of almost structureless living slime which he named "Bathybius." At a time when Darwin's theories were still under severe debate, "Bathybius" had been hailed as a living example of the primordial protoplasm. The scientists of the *Challenger* looked for it in vain, and finally discovered the answer to the puzzle. The alcohol and sea water in which the sea-bottom specimens were preserved had combined to form an amorphous precipitate of sulfate of lime. This was Haeckel's "Bathybius."

THE *Challenger* expedition made thousands of other contributions to various sciences—meteorology, hydrography, the physics and chemistry of sea water, geology, petrology, botany, zoology, geography. Murray's map of the world-wide sampling of oozes and other bottom deposits collected by the expedition has not been changed much by the many subsequent explorations. The *Challenger*'s crew perfected the method of "swinging the compass" to get accurate magnetic readings. The voyage established the main contour lines of the ocean basins and disproved the myth of the lost continent Atlantis. It yielded the first systematic plot of currents and temperatures in the oceans, and showed that the temperature in each zone was fairly constant in all seasons.

The achievement of the *Challenger* was tremendous: a barrier had been broken and the world of the depths explored. In a sense the *Challenger* had answered the question that had echoed down the ages in the words of Ecclesiastes: "That which is far off and exceeding deep, who can find it out?"

THE VOYAGE OF THE CHALLENGER - Three Level Guide

Level I. Directions: Read the statements carefully. Then, as you read the selection, refer back to the statements in the guide and check those that you believe say what the author said or paraphrased in the selection. The page, column and paragraph are given for each statement to help you refer to the selection more easily. Be ready to support the statements you have checked and explain what is inaccurate about the statements you have not checked.

✓ 1. On its voyage, the Challenger sounded the depths of every ocean except the Arctic and laid the foundation for the modern science of oceanography. (20, 1, 1)

____ 2. Before the Challenger, many soundings had taken place. (20, 2, 1)

✓ 3. The deepest sounding hit by the Challenger was 26,850 feet. The deepest sounding made, up to the time of this article, was 34,440 feet. This sounding was made in the Mindanao Trench off the Philippines in 1950. (23, 2, 0)

____ 4. The results of the voyage were never published. (23, 3, 1)

✓ 5. The voyage took place at a time when every new discovery was an exciting prize to be fitted into the evolutionary table. (24, 1, 1)

✓ 6. The Challenger demonstrated that the oceans were teeming with unknown life waiting to be classified. (24, 1, 1)

____ 7. Due to the voyage of the Challenger, it was decided that a major part of the ocean floor was covered with a thin layer of almost structureless living slime called "bathybius." (24, 2, 1)

____ 8. The voyage proved the myth of the lost continent Atlantis. (24, 3, 1)

Level II. Directions: The statements below may or may not be true, based upon what the author implies. Check those statements that you feel can be supported by the selection. The page is given for each statement to help you in referring to the selection. Be ready to support your opinions.

____ 1. Life on board the Challenger was a constant adventure for the crew. (21)

✓ 2. Discoveries and interests in all of the fields of science had set the stage for a voyage of discovery like that of the Challenger. (24)

✓ 3. The discoveries of the *Challenger* encouraged the oceanographic studies that have led to our present knowledge of the sea. (24)

Level III. Directions: Read each statement below, relating the details and your interpretations drawn from the selection to ideas and experiences you've had in reference to the topic. Check the statements that you agree with.

____1. Scientific expeditions like that of the *Challenger* or recent space probes are of little practical value.

____2. The best way to sound the depths today is with a hemp rope.

____3. Since the *Challenger* sounded the depths of almost all of the oceans, there is little need for further soundings.

✓ 4. The voyage of the *Challenger* sought to answer questions of an intellectual nature.

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PHYSICAL FACTORS: The Ocean Floor

47

TEACHER BACKGROUND - The Ocean Floor

"The Ocean Floor" serves as an introduction to physical oceanography. A look at the bottom shapes, forms, and processes is followed by readings and activities dealing with the water itself, and with the surface. Our knowledge of the sea floor has increased tremendously in the last few years. Geologists are now busy studying the ocean floor in a search for clues to the origin and evolution of the continents. Exploration and exploitation of the mineral deposits from the ocean floor and from beneath the ocean floors is increasing at a tremendous rate. The ocean floor has tradionally been viewed as a "commons", an area which all men from all countries may use but which none may own. This view is being challenged as ocean mining companies lay claim to vast tracts of the ocean floor and simultaneously ask their governments to protect the miners' interests in these claims. While debate at the United Nations takes place over division of the resources of the ocean floor great consortia of mining companies are exploring and laying claim to the mineral rich areas of the ocean bottom. The differences between these claims and the wishes of the developing nations have yet to be resolved. The rush to exploit the ocean floor has just begun. We can be sure that the problems that arise from that rush will have to be faced and answered by our students at some future date.

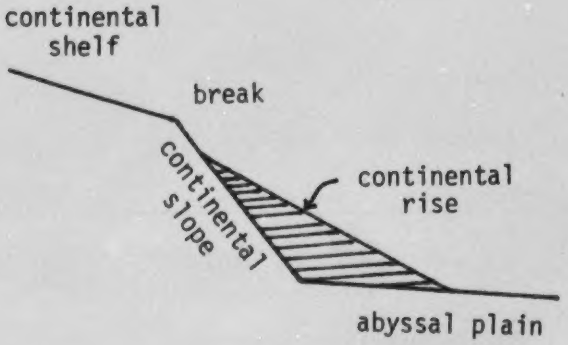
Duplicate the text pages. One set is recommended per student. This activity lends itself well to individual work. Supplement the text with audio visual aids, if possible. Provide an opportunity to discuss the concepts stressed in the text and to provide answers to the text questions.

KEY - text questions

1. Sounding the depths of the ocean means measuring the depth of water over a particular spot. Sounding was traditionally done with lines weighted with lead.

2. Topography of the ocean floor refers to its shape or contour
3. The two major divisions of the ocean basins are: the continental margin and the deep sea.
4. The continental slope begins at a depth of about 250 meters or 0.25 kilometer (800 feet). The answer comes from the illustration.
5. The continental margin runs into the deep sea floor at about 4.75 kilometers in depth (about 15,400 feet).

   The following schematic diagram may be helpful in illustrating the relationship of the three parts of the continental margin:



The boundary between the continental shelf and the continental slope is marked by a sharp break in contours. The continental rise is actually a wedge of sediment from the continents built up between the continental slope and the abyssal plain.

6. a. The deepest area shown is about 3000 fathoms (18000 feet).
   b. The Andes are about 3000 fathoms high (18,000 feet). If we put the highest Andes mountains in the deepest part of the cross section they would just reach the surface.
   c. The mid-Atlantic ridge rises to within about 1200 fathoms of the surface.

KEY WORDS

abyssal plain
average
basin
continental margin
continental rise
continental shelf
continental slope
deep sea
echo sounders
lead lines
mid-Atlantic ridge
ridges
seamounts
sonar
sounding
topography

THE OCEAN FLOOR

For hundreds of years, sailors have criss-crossed the oceans. Yet, it is only within the last few years that it has been possible to chart the topography over which they traveled.

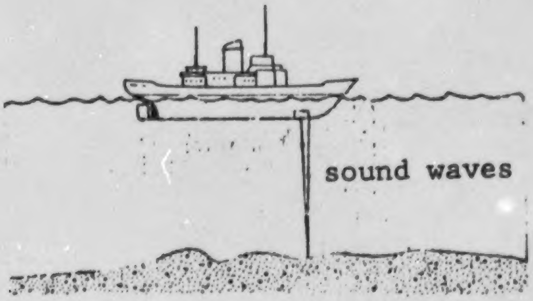
ARCTIC OCEAN
ATLANTIC OCEAN
PACIFIC OCEAN
PACIFIC OCEAN
INDIAN OCEAN

THE OCEANS

Pioneer ocean scientists sought to discover the shape of the ocean bottom by sounding with lead lines. A rope marked in meters and with a weight on one end was lowered over the side. The length of the rope over the side was noted when the bottom was reached. The length of rope was equal to the depth at that point. Sounding with a rope is difficult and time consuming. The ship has to stay in one spot so the rope will be straight. Since the average depth of the oceans is over two miles, the lowering of the rope takes a long time. Storing the rope is also a major problem.

1. What is meant by "sounding" the depth of the ocean?

If we had to rely on lead line soundings to determine the shape of the ocean floors, we would still know very little about its topography. After World War I, a major breakthrough occurred: sonar. Sonar, or echo sounders, use sound waves in place of the line. A sound wave is produced on board the ship. The wave travels to the bottom, is reflected and returns to the ship. The amount of time for the wave to make the round trip is recorded. Since we know how fast sound travels in sea water, we can determine the depth. Modern depth sounders employ a strip-chart recorder on which a continuous graph of ocean bottom topography is drawn while the ship steams on its course.

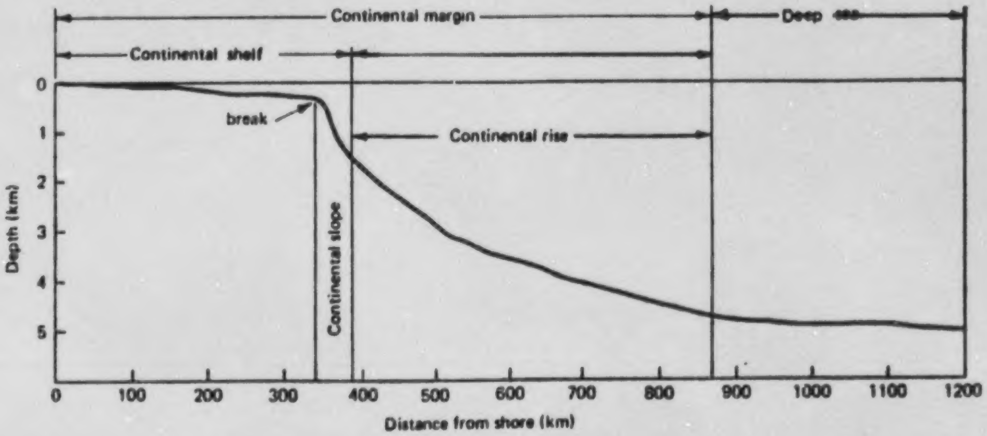


ECHO SOUNDER

$$\text{depth} = \frac{\text{time down and back} \times \text{speed of sound}}{2}$$

2. What is meant by "topography of the ocean floor?"

What have we found? The floor of the oceans is not flat. It is covered with mountains, valleys and plains similar to what we might see above the surface of the seas. We can get an idea of the depth of the oceans by considering this fact: if the continents were all scraped off, ground up, and spread over the Earth's surface, the Earth would be completely covered with a single ocean between one and two miles deep! The ocean basins are separated into two major divisions called the continental margin and the deep sea.



CONTINENTAL MARGIN

Continental margins

The continental margins are the areas where the continents merge into the oceans. Surrounding the world's continents is a relatively flat platform that extends about 350 kilometers (210 miles) from the edge of the sea. This platform is called the continental shelf.

3. What are the two major divisions of the ocean basins?

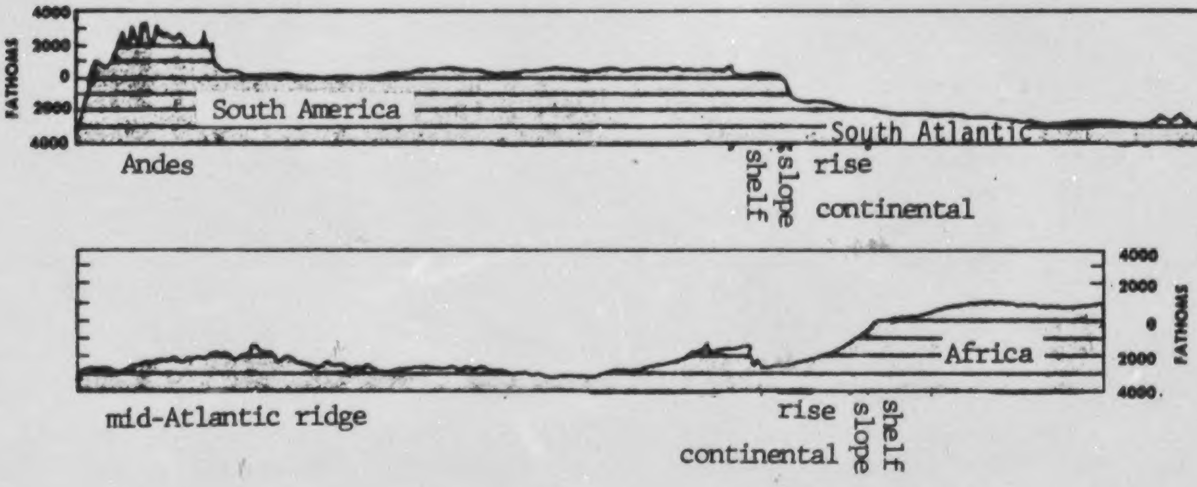
At the edge of the continental shelf, the slope increases abruptly. Beyond this edge, the continental slope and the continental rise run downward to the deep-sea floor.

4. At about what depth does the continental slope begin?

5. At about what depth does the continental margin run into the deep sea floor?

Deep-Sea Floor

The deep-sea floor is not uniform. Mountains called seamounts rise from the floor. Some rise above the surface forming islands. There are trenches deeper than Mt. Everest is high. Flat abyssal plains rise to form oceanic ridges. In some areas the surface is cracked and folded. The picture below shows a cross section of the land and ocean bottom from South America to Africa. The surface of the ocean floor is often more rugged than the surface of the continents.


4000
2000
0
2000
4000
FATHOMS
South America
South Atlantic
Andes
shelf
slope
continental
rise
mid-Atlantic ridge
continental
rise
slope
shelf
Africa
4000
2000
0
2000
4000
FATHOMS

6. Use the South America to Africa cross section to answer the following questions.
    a. How deep is the deepest area shown?
    b. How tall are the Andes mountains?
    c. How near the surface does the mid-Atlantic ridge rise?

Knowledge of the ocean floor is giving us information that may help explain the history of the continents and oceans. In addition, knowledge of the resources of the ocean floor is becoming increasingly important as man looks to the sea for minerals and for food.

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TEACHER BACKGROUND - Bathymetric Analysis

Bathymetric maps are used by navigators, fishermen, and others interested in the shape of the ocean bottom. These maps correspond to the topographic maps used to study dry land forms. "Bathymetric Analysis" provides information and activities to familiarize your students with the techniques employed in bathymetric map making and utilization. Contour maps are an efficient way to present three dimensional information in two dimensions. Their effective use, however, requires practice.

Duplicate the activity pages. One set is recommended per student. If you are not familiar with contour mapping, consider performing the activities yourself before your class embarks on them. Emphasize the point that equal depths are connected, but that the equal depth contour lines must never cross one another. This activity may be performed independently or in small groups. Both approaches have merit and the one you choose will depend upon your particular circumstances. Since mistakes are bound to occur, have your students complete the activity in pencil and plan to have extra copies of the map pages available.

KEY

See attached maps.

Results and interpretation

1. See attached map key 2.
2. There are several reasons you would want to study the map before you began: to avoid running aground on a shallow bottom; to avoid catching your gear on the bottom; to locate areas of the depth at which you expect to catch the particular fish you are after, etc.
3. Geologic features of a small extent are most easily missed. For example, small, deep valleys, or round cone-shaped mountains with a relatively small

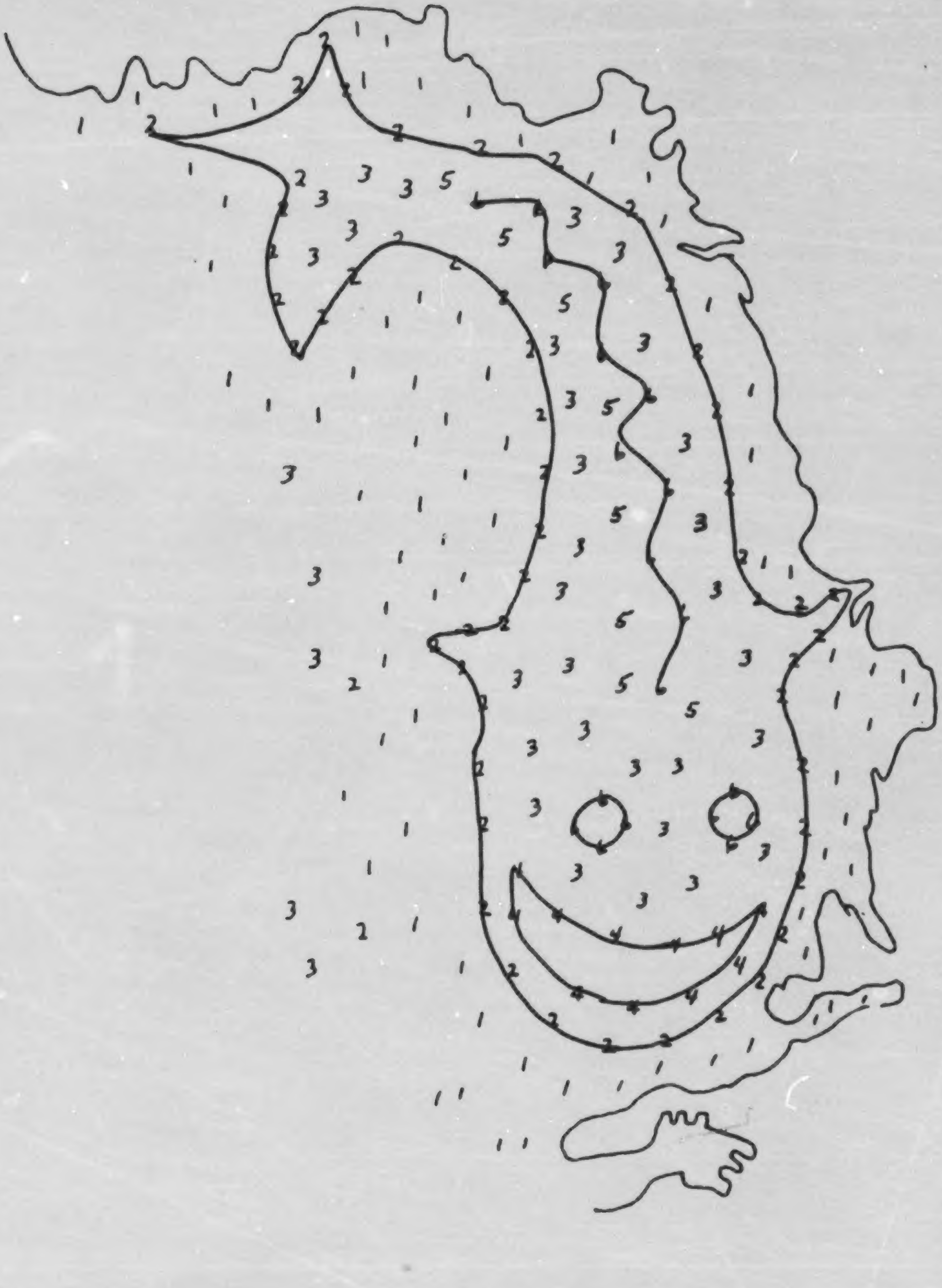
circumference. These are easily missed because the ship gathering the depth data must travel over the surface feature to record it. New sonar can map a wider swath, but it is still possible to miss small features as the boat travels back and forth across an area.

4. a. The answers here depend upon the student results, but it is unlikely that the maps will be exactly the same.
   b. There are several things that might explain the differences: there is a considerable amount of choice regarding the precise location of the lines; it is possible to incorrectly connect depths; etc. A discussion of the possible sources of error is worthwhile at this point. Ask your students how the errors might be minimized. The advantage of averaging data and comparing results should emerge from such a discussion.
5. The first charts were made for coastal regions because these were the areas first ventured into by explorers and because these are the areas in which one is most likely to encounter problems from shallow bottoms.

KEY WORDS

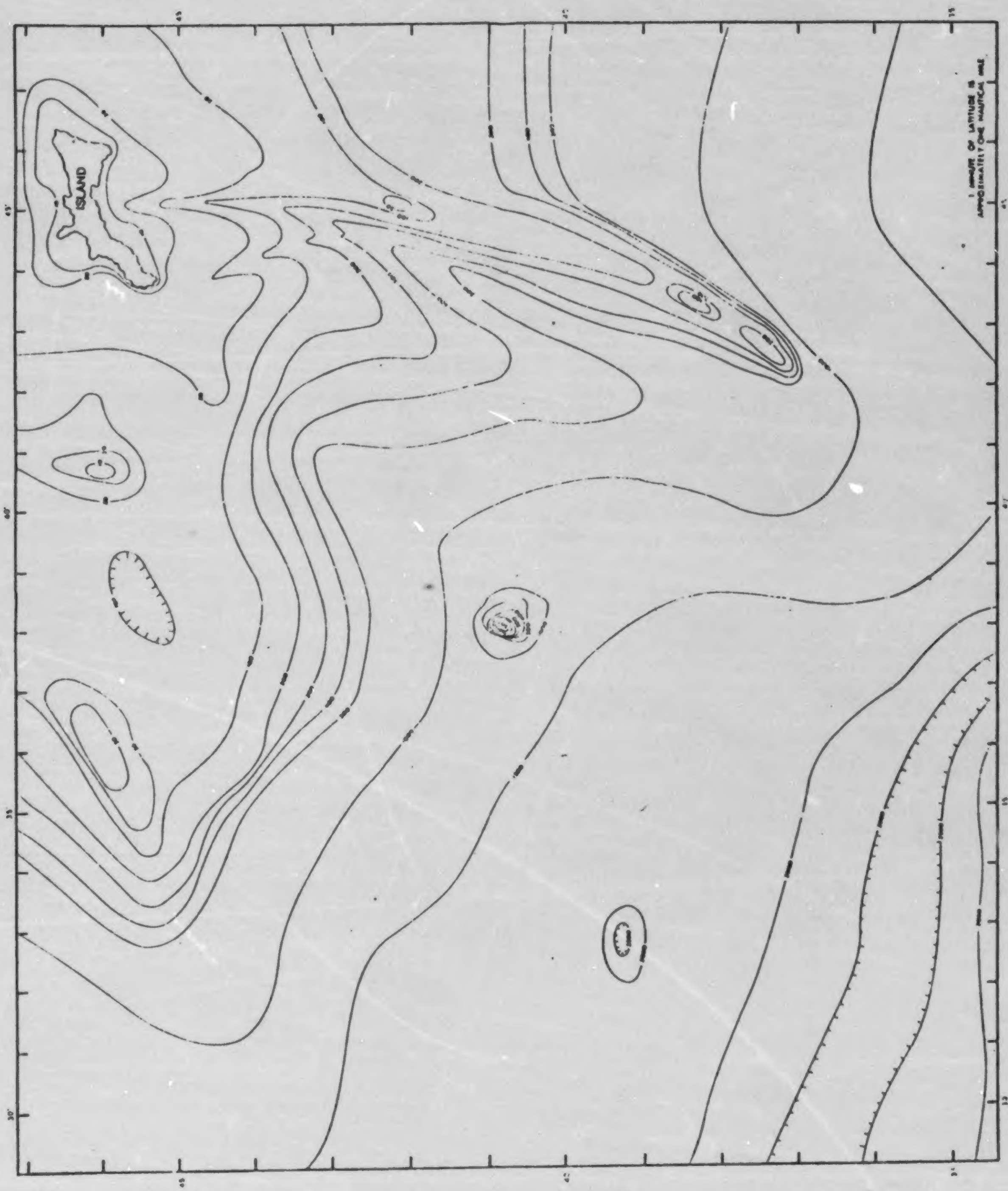
bathymetric
contour
depression
geologic feature
island shelf
ridge
navigational
seamount
soundings
submarine canyon
submarine valley
trough

KEY MAP 1



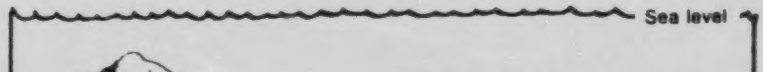
MAP 2

BATHYMETRIC ANALYSIS SOLUTION (GENERALIZED)


ISLAND
1 MINUTE OF LATITUDE IS APPROXIMATELY ONE NAUTICAL MILE

BATHYMETRIC ANALYSIS

Ocean soundings or bathymetric data give us information about the changes in depth and the shape of the ocean bottom. The sounding notations found on navigational charts help us to visualize the shape of the bottom features. To prepare a navigational chart, many soundings are made and recorded. Oceanographers then draw lines connecting all of the points having the same depth. These lines are called contour lines and they are drawn at regular depth intervals. The completed set of contour lines show the shape of underwater ridges, mountains, and valleys. The lines also show the depth of these features. Successive contour lines that are far apart on the map show a gentle slope. Lines that are close together indicate a steep slope. In the case of cliffs the lines may even appear to run together. The figure below shows the way in which contour lines express depth, form, and slope.


Sea level
350
300
200
250
400
450
500
550
600
600
500
550
650
700
800
750
850
900
400
350
300
250
350
400
400
450
500
550
600
650
700
800
750
850
900

The sketch represents a submarine (underwater) valley. The valley lies between two hills. In the foreground is a submarine plain. The hill on the right is well rounded and has a ridge extending northwest.

The hill on the left slopes steeply and has two peaks. On the map, each of these features is represented directly beneath its position in the sketch by contour lines.

The contour lines are labeled as shown. The chart should state whether the units of depth used are feet, meters, or fathoms.

Materials:

Pencil
Maps

Procedure:

1. Using map 1, connect areas of equal depth with pencil lines. Connect the 2, 4, and 6 fathom lines.

REMEMBER: EQUAL DEPTH CONTOUR LINES NEVER CROSS ONE ANOTHER!

2. Plot the equal contours on Map 2. Too many contour lines is confusing while too few may be misleading. For this chart use the following contours (in fathoms)

10
20
50
100
200
300
400
500
1000
1500
2000
2500

Remember that a contour is a line connecting all points at the same elevation and closes upon itself. The contours of smaller features will close within the area of the chart. The contours of the larger features may not close in the chart area.

3. Answer the questions in the Results and Interpretation Section.

Results and Interpretation:

1. Label the following features on your Map 2:

    seamount
    depression
    trough
    ridge
    island shelf
    submarine canyon

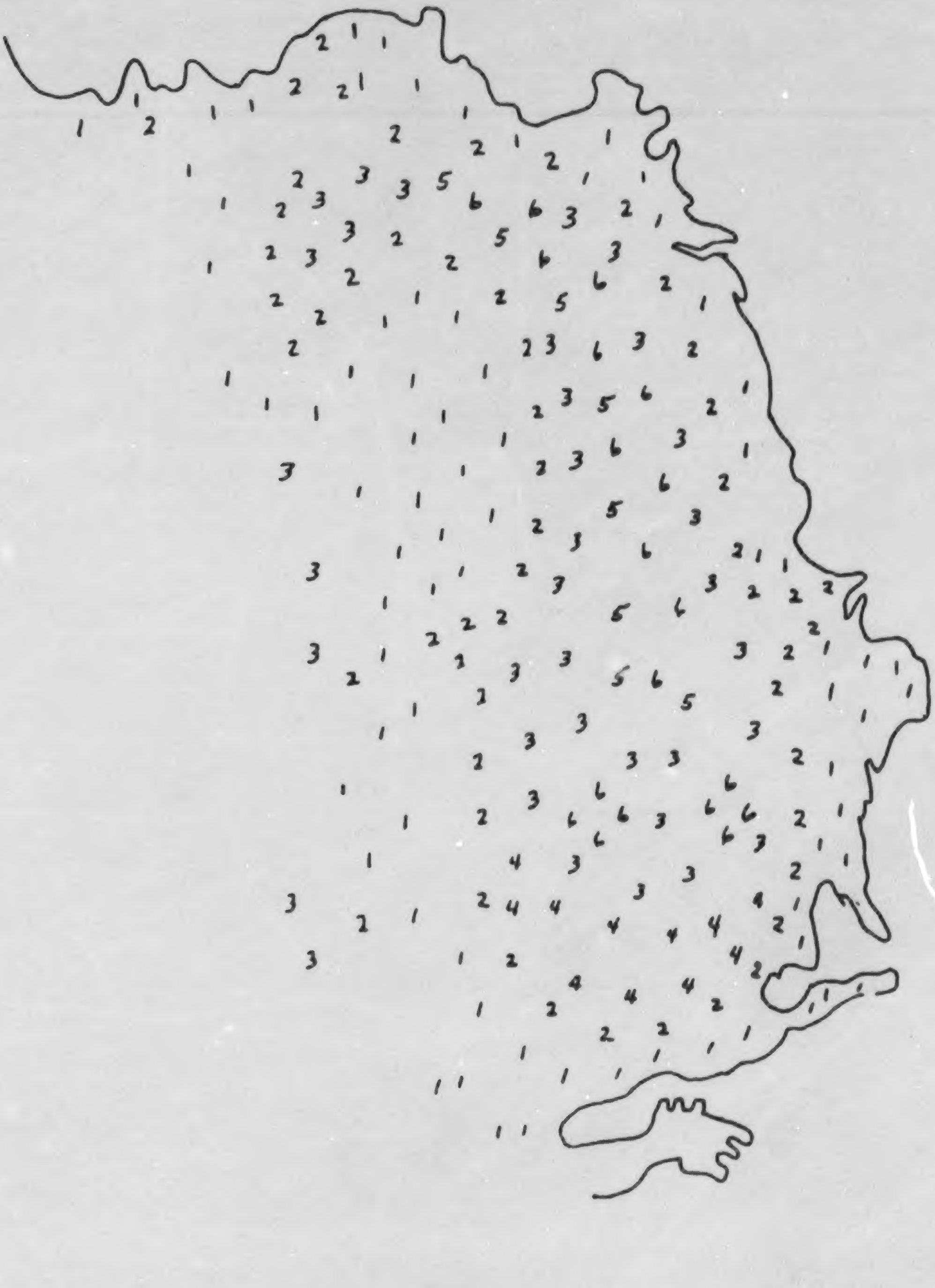
2. Imagine yourself as the skipper of the fishing boat Evergreen. You hear over your radio that the fishing for bottom fish is good in the area shown on Map 2. What are two reasons you would want to study Map 2 before you began fishing?

3. When mapping an area of the seafloor it is possible to miss geologic features. What kind of features are most likely to be missed?

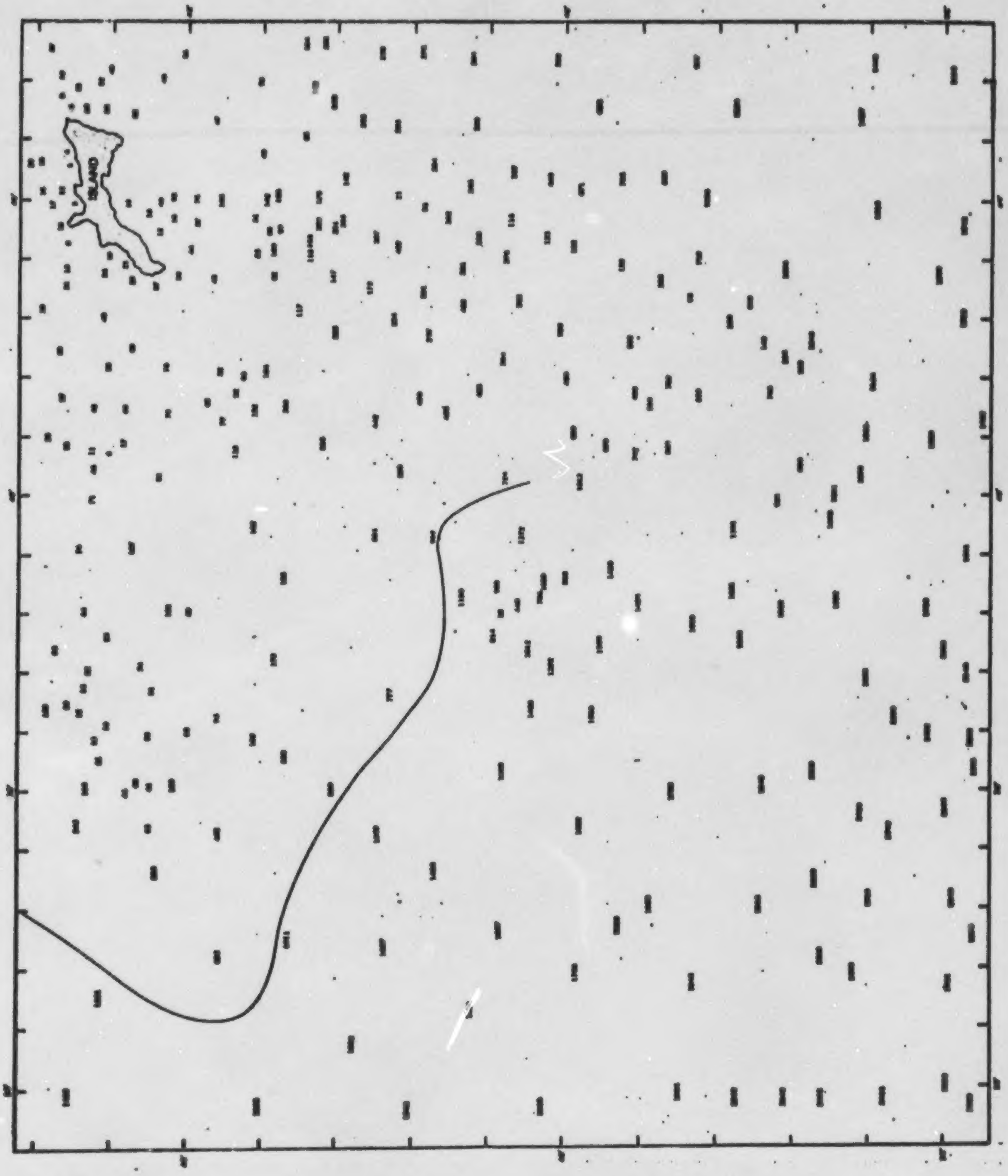
4. Compare your bathymetric Map 2 with those of others in your class.
    a) Are the maps exactly the same?
    b) If you find differences, what are two possible causes?

5. The first bathymetric charts were made for coastal areas. What are two reasons that could account for this fact?

MAP 1



MAP 2
BATHYMETRIC ANALYSIS EXERCISE



PHYSICAL FACTORS: Tides

TEACHER BACKGROUND - Oceans in Motion: Tides

The tides affect all seashore life. The tidal zone is the most dynamic of all marine environments. Wave action combined with exposure to drying by the sun make the sea beach a difficult place to live. It is likely that it is from this zone that the evolution of land animals and plants must have occurred. Ill adpated forms could not have survived. Most people have heard about the daily rise and fall of the tides. Likewise most people have heard that the tides are caused by the gravitational forces of the sun and moon. Tides affect navigation and, as such, are traditionally of great importance to sea going man.

In order to study the tides, observations of the time of the rise and fall of the tide each day must be recorded for a long period of time. This data reveals patterns and long term averages. Using these long term averages, predictions can be made for the future. The Oregon State University Extension Marine Advisory Program publication "Understanding tides" is included in this background to provide additional information to help you in teaching this and the following sections.

Duplicate the text pages. One set per student is recommended. Tides tend to be somewhat confusing to students. As such, be aware of possible problem areas for your class and provide information and assistance when needed. There are several good films which can be effectively employed as teaching aids. These include: Tides of the Ocean by Academy Motion Pictures, and Ocean Tides an EBEC film.

"One Step Further" introduces some of the mathematical concepts involved in calculating tidal heights. The material is presented in a step-wise fashion and most students should have little trouble completing this section. "More One Step Further...." introduces the concept of stationary waves and the effect of basin shape on the tides. Landform and basin shapes influence the tides.

"Oceans in Motion: Tides" provides background information which is helpful in understanding several activities dealing with the tides, including:

Using the 24 Hour Clock
Types of Tides
Tide tables
Tide Tables Too?
Tide Action on the Beach, and
How High's the Water?

The concepts involved in these activities are varied but all are tied together by the tides.

KEY - text questions

1. The tide is the regular rhythm of the rising and falling of the ocean waters. As a point of interest, Webster's New Collegiate Dictonary defines "tide" as "the alternate rising and falling of the surface of the ocean and of water bodies (such as gulfs and bays) connected with the ocean that occurs twice a day and is caused by the gravitational attraction of the sun and moon occuring unequally on different parts of the earth".
2. People who lived along the coast noticed that:
    a. there were two high tides every day;
    b. there were two low tides every day;
    c. there were two especially low tides every 29 days;
    d. there were two especially high tides every 29 days; and
    e. the regular changes in the tides followed the changes seen in the phases, or light/dark patterns, of the moon. (Any four observations will do).
3. The bulge at A is due to the gravitational pull of the moon upon the earth.

The bulge at B is due to the centrifugal force of rotation of the earth.

4. High tides come 52 minutes later each day because the moon rises later each day, it takes a point on the earth about 52 additional minutes each day to catch up and to pass through the moon's two tidal bulges.
5. The tidal range is the difference between the successive high and low. Or 9.7 feet minus 0.3 feet = 9.4 feet.
6. Spring tides occur when the moon and the sun align with the earth. The attractive forces due to gravity are additive and the tide rises higher and falls lower than the average.
7. Neap tides occur when the moon and sun are at right angles with respect to the earth. The attractive forces due to the gravity of the sun and the moon work against each other. The tide rises and falls less than the average.
8. The variation we see in real life comes from the fact that the distribution of the oceans and land masses is irregular. This irregularity causes the oceanic basins of the world to respond to tide producing forces as individual closed basins.
9. This is a chance for your students to apply what they have learned. Logical difinitions can be derived from the text. Tideland is land that is covered by water at high tide and uncovered at low tide. Tide pool is a pool of water left behind when the tide recedes.

One Step Further.....

1. a. The tide producing force of the sun due to mass is 27,000,000 times greater than that of the moon.

   b. The tide producing force of the sun due to distance is $(\frac{1}{389})^3$ or $(\frac{1}{389} \times \frac{1}{389} \times \frac{1}{389})$ which equals $\frac{1}{58,963,969}$ times the force of the moon.

c. The combined forces equal:

$$\underline{27{,}000{,}000} \times \frac{1}{58{,}863{,}869} = \frac{27{,}000{,}000}{58{,}863{,}869} = .46$$

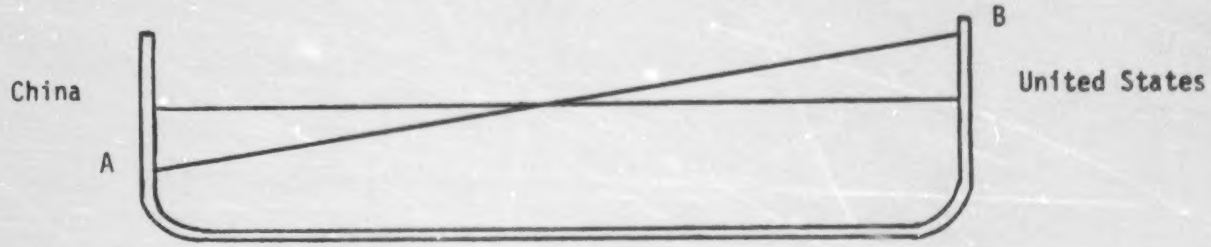
The tide producing force of the sun is .46 or 46% of the tide producing force of the moon. In other words, the moon plays more than twice the role of the sun in producing the earth's tides.

d. The sun's tide producing force is .46 times that of the moon.

e. The moon is the heavenly body most responsible for the tides.

More One Step Further.....

1.



2. a. The United States is having a high tide.

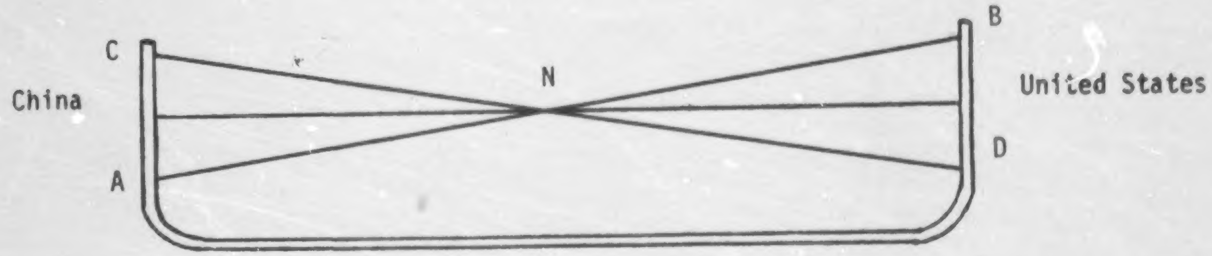
b. High tides would be occuring all the way from B to N

c. China is having a low tide.

d. Low tides would be occurring all the way from A to N.

e. The water level at N remains the same, it does not change.

3.



a. China is having a high tide.

b. High tides would be occurring all the way from __C__ to __N__.

c. The United States is having a low tide.

d. Low tides would be occurring all the way from __D__ To __N__.

e. The water level at N remains the same, it does not change.

4. A nodal line is a line along which there is no (or little) tide change.

KEY WORDS

basin

centrifugal force

ebb

flood

force

gravitational pull (force)

gravity

high tide

low tide

mass

neap tides

nodal line

spring tides

stationary wave

tide

varies directly

varies inversely

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Understanding tides

Another title in the series

Learning about the ocean

by R. Lawrence Swanson
Manager, New York Bight Project
Marine EcoSystems Analysis (MESA)
National Oceanic and Atmospheric Administration
Stony Brook, New York

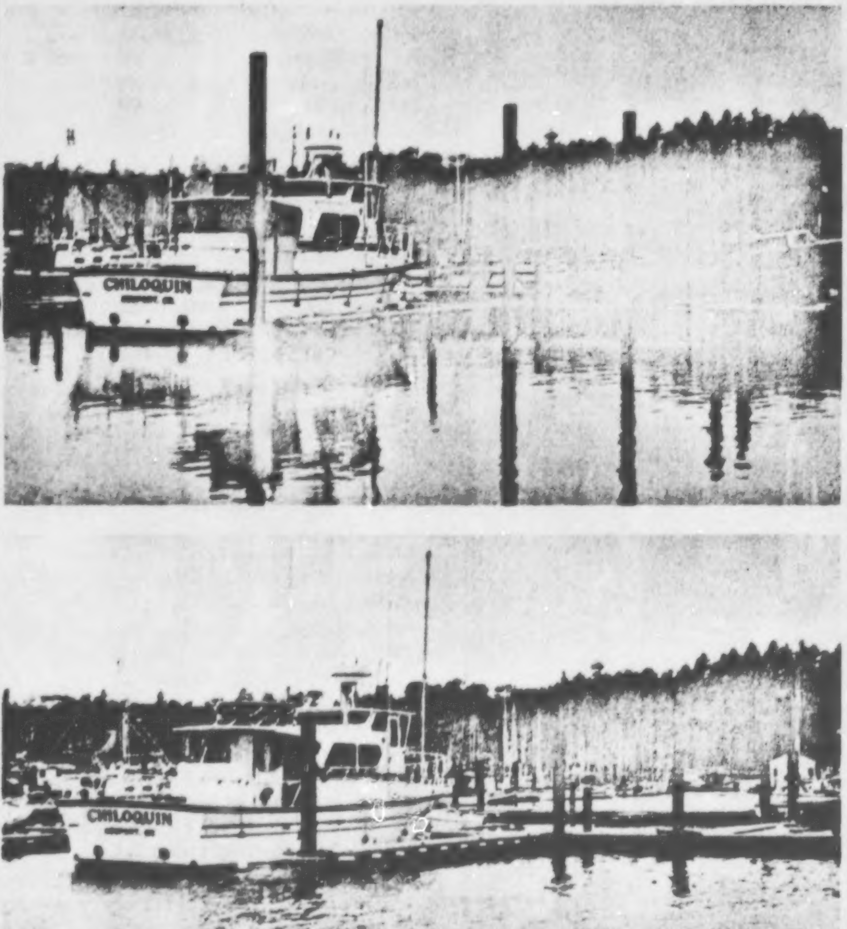

Figure 1.—*The Moon's and the Sun's gravitational tugs on the Earth cause the oceans to bulge in two places. As the Earth turns on its axis, the ocean bulges and lows rise and fall along coastlines as daily tides. In these two views of the Newport, Oregon, harbor (photographed seven hours apart on the same day), the fall and rise of the tide show in the relative heights between the floating boats and docks against the fixed pilings and shore objects.*

The tide is the periodic daily or semidaily fluctuation of the sea surface. Ocean tides occur worldwide, but the degree of fluctuation varies from imperceptible to many meters.

The first documented reference to tides was in the fifth century B.C. by the Greek historian, Herodotus, who observed characteristics of the tide in the Red Sea. In the next century, Pytheas noted that the motion of the Moon and the rise and fall of the tide were related. Apparently this observation was an outgrowth of his travels to the British Isles, where the range of tide is many times that of his native Greece.

As human horizons expanded, knowledge of physical sciences and, thus, understanding of tides also increased. From the first, tides have been considered important to navigation. Knowledge of tides was essential for growth and development of coastal communities that flourished as a result of early commerce. Wharves, buildings, and other structures had to be constructed with the ever-changing water level in mind (figure 1).

Today, it is even more important that complicated but rhythmic tidal motions and their associated forces be understood as we build closer to the waterfront or shore. Bridges and pipelines connect points of land once considered inaccessible. Bays and harbors have to be protected from the forces of the sea, of which the tide is a major contributor. Supertankers, no longer able to enter many existing ports, have to be handled on the continental shelf, requiring deepwater loading facilities in exposed areas. Consequently, we need to understand not only tides in coastal areas, but also those of the open ocean.

**Oregon State University
Extension Marine Advisory Program
A Land Grant / Sea Grant Cooperative
SG 25 June 1977**

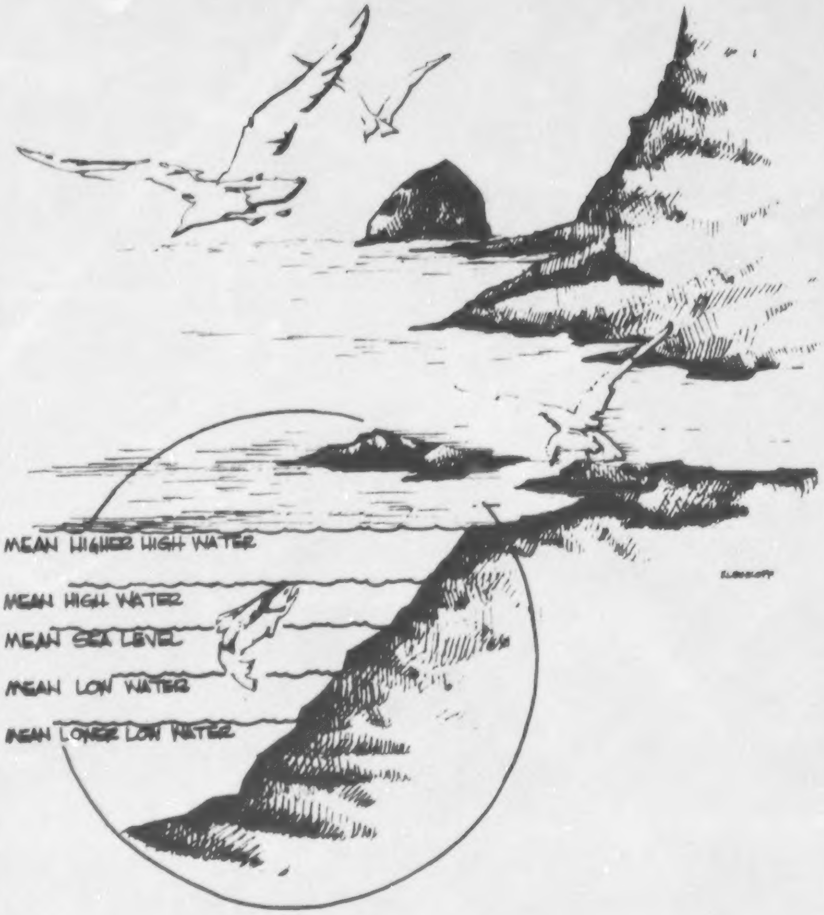

Figure 2.—*The height of the ocean's surface rises and falls with predictable regularity. The means of these periodic high- and low-water conditions are defined as tidal datums. The tidal datums are relative (that is, related to one another) and identified as shown above.*

As people seek to better manage the wastes they dump into streams, rivers, and estuaries, they are calling on oceanographers for more information concerning estuarine and coastal circulation. This is essential for establishing intelligent but practical waste management procedures. Tides play an important role in determining rates of dilution, mixing, and flushing of these coastal waters.

Defining seaward boundaries is another issue with relevance for tide knowledge. In the offshore oil industry, for example, state-Federal boundaries must be precisely defined for determining which jurisdiction may claim taxable revenue. Similarly, as in past years along the Oregon coast, private-state boundaries are becoming critical issues. Since the coastline is not static and instead is constantly undergoing change, boundaries are difficult to demarcate. As a result, boundaries are defined in relation to mean tide elevations.

To help keep track of these mean tide elevations and use them, certain standard references have been established. The most effective references are the *tidal datums,* which are simply fixed references from which we reckon heights or depths. There are a variety of such datums, called by different names, such as *mean low water, mean lower low water, mean high water, mean higher high water,* and *mean sea level.* Each of these tidal datums may be determined in relation to a time period of a specified length, called a *tidal epoch.* These tidal datums can be located on the ground and mapped (figure 2).

Elementary tidal theory—the equilibrium tide

The cause-and-effect relationship between the Moon and tides remained a mystery until 1687, when Isaac Newton published his classic book, *Philosophiae naturalis principia mathematica,* which stated his laws of gravity. Newton's work, along with that of Daniel Bernoulli in 1740, led to the *equilibrium theory of tides*—a basis for understanding simple tidal generation.

The Moon as primary force. Although a number of forces act to produce tides, for the moment we will consider only the forces caused by the Moon. Newton's law of gravitation states that two bodies are attracted toward each other. The strength of this attraction depends on the mass of the bodies and the distance between them. (Two bodies are attracted directly proportional to the products of their masses and inversely proportional to the square of the distance between them.) In the case of the Earth and the Moon, the gravitational attraction between the two is balanced by an additional force. The balancing force is the centrifugal force caused by the rotation of the Earth and the Moon about the center of mass of the Earth-Moon system.

On the side of the Earth nearer the Moon, the gravitational attraction between the Earth and the Moon is greater than the centrifugal force. On the side of the Earth farther from the Moon, the centrifugal force is greater than the gravitational attraction between Earth and Moon.

Thus, the tide-generating forces try to create two tidal "bulges" on opposite sides of the Earth along a line connecting the Earth's center and the Moon's center. Because there are two bulges, there are generally two tides per lunar day (figure 3).

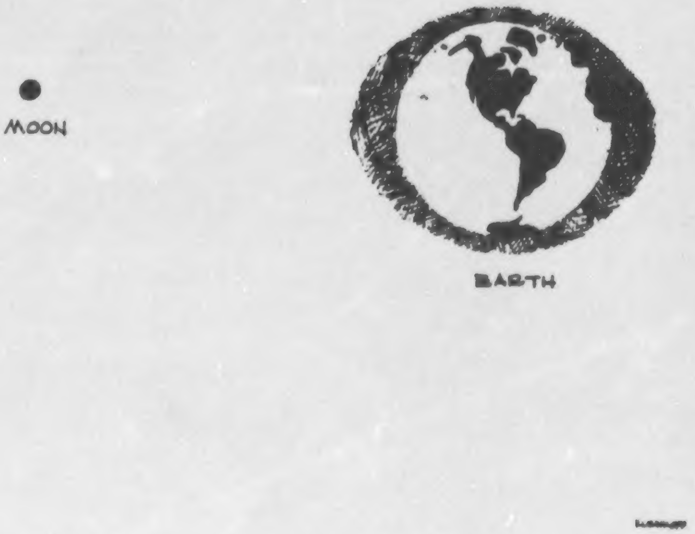

Figure 3.—*Two tidal "bulges" are present on opposite sides of the Earth, formed by the difference between the gravitational forces and the centrifugal force caused by the Earth's revolution around the center of mass of the Earth-Moon system. The Earth makes one complete rotation relative to the moon every 24 hours and 50 minutes. Thus, a location on a coast moves through each of the ocean bulges in a lunar day, and there are two tides a day along most coasts.*

The Sun as secondary tidal force. Heavenly bodies other than the Moon cause tide-generating forces, but the only other body of significance is the Sun. Although it has far greater mass than the Moon, the Sun is much farther from the Earth than the Moon. Consequently, the Sun's tide-generating force on Earth is only about 46 percent as great as that of the Moon.

To understand the variations in tides as they occur over extended periods of time, consider the constantly changing relationship of the Earth, the Moon, and the Sun. Remember that the Moon orbits about the rotating Earth, and both the Earth and the Moon orbit about the Sun. In addition, remember that they do so not in perfect circles, but in ellipses, so that distances one from the other are constantly—and predictably—changing.

Remember that the Earth's axis is tilted with respect to its orbit about the Sun, and the Moon's orbit is also at an angle to the Earth's orbit. Therefore, the angular relationships between the Earth and the Moon, and the Earth and the Sun, are constantly—and predictably—changing. Now let's look at the effects of all these dynamic relationships.

The Moon and the Sun interact. Anyone who has observed tides or studied a tide table has noted that the difference between a high tide and a low tide may be greater at one time of the month than at another. The *range of tide*, or difference between successive high and low waters, varies primarily as a result of the changing positions of the Sun and Moon with respect to the Earth.

Figure 4 reminds us that as the Moon rotates about the Earth approximately once a month, it is aligned with the Sun twice a month and it is at right angles (*quadrature*) at two other times during the month.

When the Moon is on a line connecting the Earth and the Sun, we have either a new Moon or a full Moon. At this time the attractive forces of the Sun and the Moon are aligned and reinforce each other, increasing the tidal bulge. When this occurs semimonthly, the range is increased, with the high tides being higher and low tides being lower than average. These are called *spring tides* (this name implies no reference to the season of the year).

When the Moon is at quadrature, we have either a first-quarter or a third-quarter Moon. At this time the attractive forces of the Sun and the Moon are at right angles and tend to counteract one another, resulting in a decreased tidal range: high tides are lower and low tides are higher than average. These are called *neap tides*.

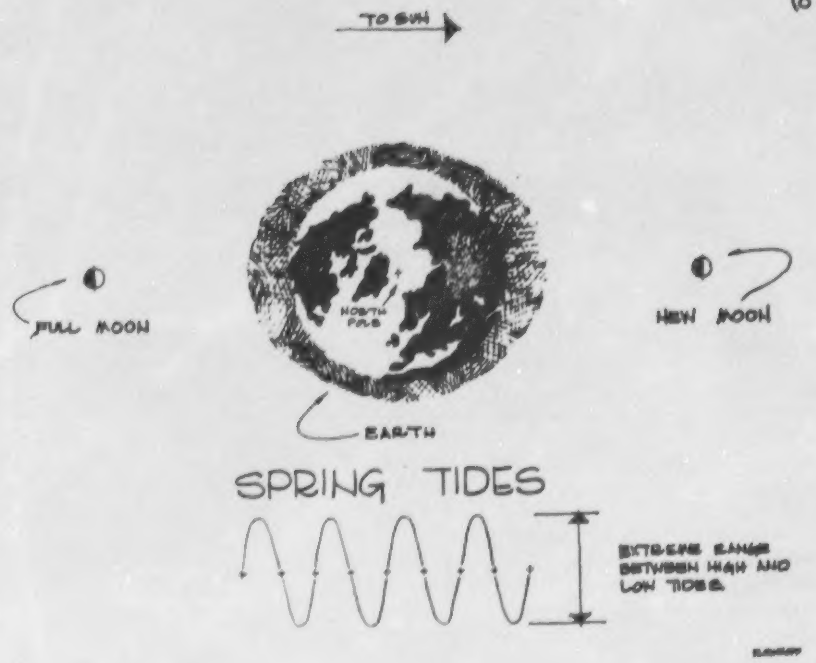
TO SUN
FULL MOON
NORTH POLE
NEW MOON
EARTH
SPRING TIDES
EXTREME RANGE BETWEEN HIGH AND LOW TIDES

Figure 4a.—*During times of full and new Moon, the Earth, Sun, and Moon are in a line; and spring tides occur.*

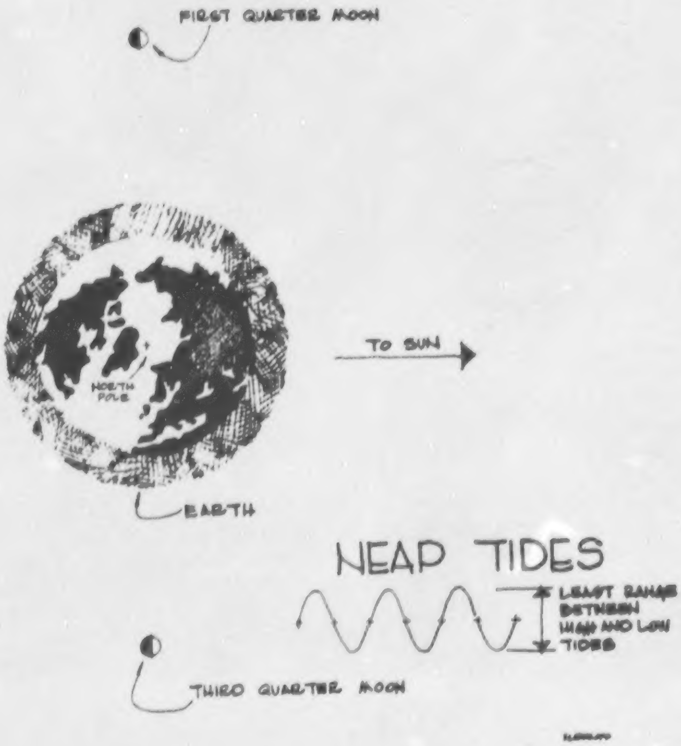
FIRST QUARTER MOON
NORTH POLE
TO SUN
EARTH
NEAP TIDES
LEAST RANGE BETWEEN HIGH AND LOW TIDES
THIRD QUARTER MOON

Figure 4b.—*When the Moon is at first and third quarter, the Moon and Sun form a right angle with the Earth; neap tides now occur.*

Effects of elliptical orbits. As the Moon moves through its elliptical orbit about the Earth approximately once each month, it passes through points nearest and farthest from the Earth. Figure 5 illustrates this phenomenon. The point nearest the Earth is called *perigee;* that farthest from the Earth, *apogee*. Tide range is increased when the Moon passes through perigee. The tide range is decreased at apogee.

As the Earth moves about the Sun, a similar situation occurs. The point when the Earth is nearest the Sun is *perihelion;* farthest from the Sun, *aphelion*. The effect of the Earth's passing through perihelion and aphelion is less pronounced than the counterparts of the Moon's motion but is of the same sort. And, of course, it occurs on a yearly basis instead of monthly.

The angular relationship. As noted previously, we observe a changing angular relationship between the Earth and the Moon, and the Earth and the Sun. The angular distance north or south of the equator is called *declination*. The changing declination of the Moon and the Sun also play an important role in modifying tides.

The Moon's declination completes a full cycle approximately every 27⅓ days. In completing this cycle, it can reach maximum values of nearly 28.6° north and south of the equator.

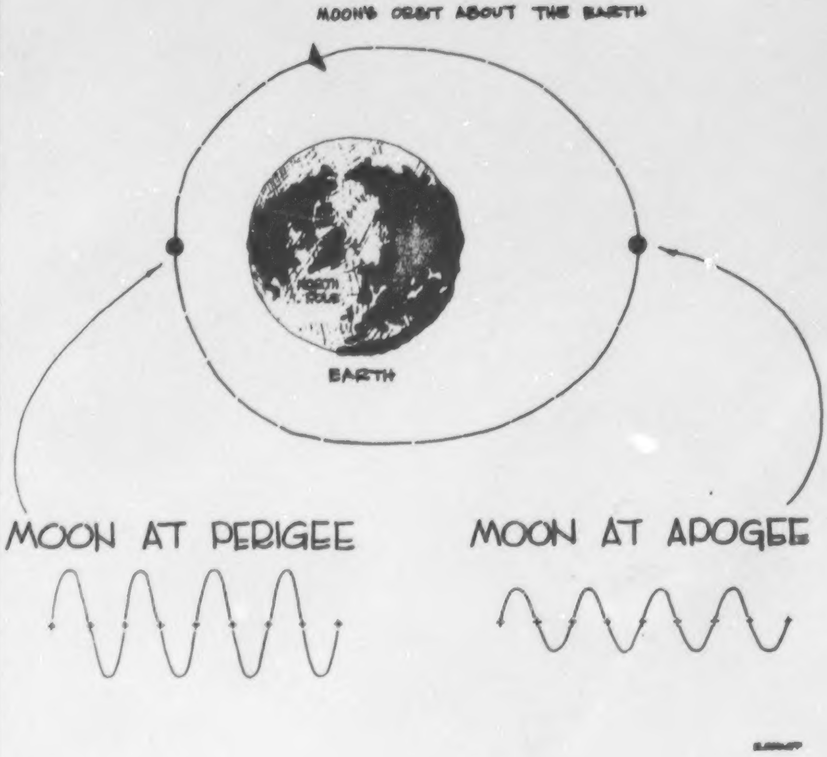

Figure 5.—*Elliptical path of the Moon orbiting the Earth. Tidal range is greater when the Moon is at perigee than when it is at apogee.*

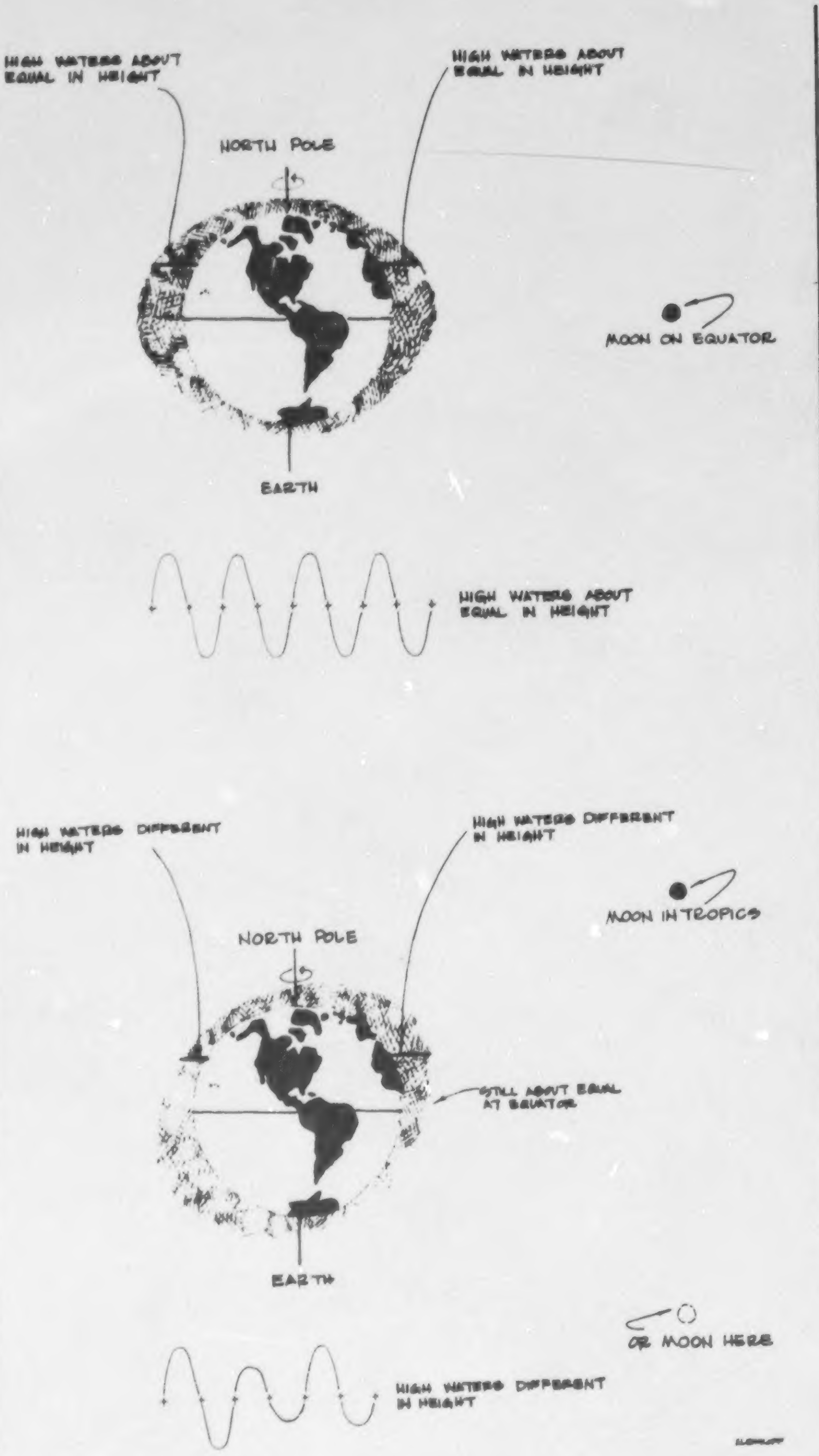
HIGH WATERS ABOUT EQUAL IN HEIGHT
HIGH WATERS ABOUT EQUAL IN HEIGHT
NORTH POLE
MOON ON EQUATOR
EARTH
HIGH WATERS ABOUT EQUAL IN HEIGHT
HIGH WATERS DIFFERENT IN HEIGHT
HIGH WATERS DIFFERENT IN HEIGHT
MOON IN TROPICS
NORTH POLE
STILL ABOUT EQUAL AT EQUATOR
EARTH
OR MOON HERE
HIGH WATERS DIFFERENT IN HEIGHT

Figure 6.—*The difference in height of each day's two high waters or of its two low waters increases as the Moon moves (declines) toward the Earth's north or south pole. This difference, called diurnal inequality, is generally greatest when the Moon is at maximum declination.*

As the Moon approaches its maximum declination (once north and once south each cycle), its attractive force is unevenly distributed with respect to the equator, as shown in figure 6. The effect is to cause a difference in the heights of succeeding high waters and succeeding low waters in the same day. The difference between high waters and between low waters is known as *diurnal inequality* (diurnal means "daily").

Diurnal inequality is generally at a maximum when maximum declination occurs, producing what are called *tropic tides*. Diurnal inequality is at a minimum when the Moon is over the equator, causing *equatorial tides*. As one would expect, tropic and equatorial tides each occur twice every cycle of 27½ days.

Interaction. Of course, all of these astronomic movements go on simultaneously in cycles whose lengths vary one from the other. Thus, their combined effects may be to enhance or nullify one another. In a later section, we will note how all combine to affect clamming tides in Oregon.

The real tide varies from theory. In discussing equilibrium theory, we assumed the Earth was a smooth surface completely covered by a fluid in equilibrium with the tide generating forces. We ignored the effects of friction in the movement of fluid, inertia, depth of the ocean, presence of continents, and rotation of the Earth. Of course, all of these factors must be considered when we study the tides as they really are. If equilibrium assumptions were valid, tidal response would be simultaneous with the tide-producing forces.

Because this is not the case, the time of high tide varies considerably throughout the world's oceans in relation to when the Moon passes over the local meridian. (A meridian is a great circle of the Earth passing through the poles and any given point on the Earth's surface.) The height of tide also cannot be explained entirely by the simplified theory. Consequently, equilibrium theory does not fully account for the observed tidal phenomena. Instead it only gives us insight into the basic causes and fluctuations.

Predicting tides. When we deal with nature, one of our prime objectives is to predict future events. Tides are no exception. In predicting the behavior of the ocean, we generally can predict tides better than any other natural phenomenon, at least in coastal areas where knowledge of the tides is most essential.

Our ability to predict tides is good not because we understand the theory of tides better than that of other oceanic events, but because the tide is determined by the Sun and Moon, movements of which are well-ordered in time and space.

The *marigram*, or graphic record of the rise and fall of the tide, at a given location, is a continuous function that is periodic, readily lending itself to a curve-fitting procedure and thus a forecast of tidal heights.

Types of tide

A marigram is distinctive for a specific location, but there are general characteristics of the tides throughout the world that permit us to establish a classification system. Figure 7 shows examples of marigrams for *diurnal*, *semidiurnal*, and *mixed* types.

Diurnal. A tide is diurnal if, during the period of a lunar day (of 24 hours and 50 minutes), there occurs only one high water and one low water. Diurnal tides are primarily caused by the changing declination of the Moon and are most pronounced at the times of maximum declination (figure 6). These tides are found in the northern Gulf of Mexico and in southeast Asia.

Semidiurnal. The semidiurnal tide is that which is most commonly found throughout the world. It is characterized by two high waters and two low waters in the lunar day. The elevations of succeeding high waters and succeeding low waters are nearly the same. A semidiurnal tide is found on the East Coast of the United States, for example.

Mixed. Just as with a semidiurnal tide, the mixed tide is marked by two high waters and two low waters in a lunar day. Succeeding high waters, low waters, or both are generally different in height, however. These differences are known as diurnal inequality. Remember the inequality is caused by the changing declination of the Moon. Mixed tides are common to the West Coast of the continental United States, Alaska, and Hawaii.

Phenomena associated with tides

Marigrams may show changes in water level that are not due solely to tidal movement caused by heavenly bodies. Among these tidal phenomena are *meteorological effects*. Also, in any discussion of tides the related horizontal movement of water, or tidal currents, should be mentioned.

The meteorological effects. Water responds to external forces applied to it. Two forces always at work in varying degrees on the water surface are wind and direct barometric pressure. They combine to effect a change in the elevation of the water surface known as wind setup or *storm surge*.

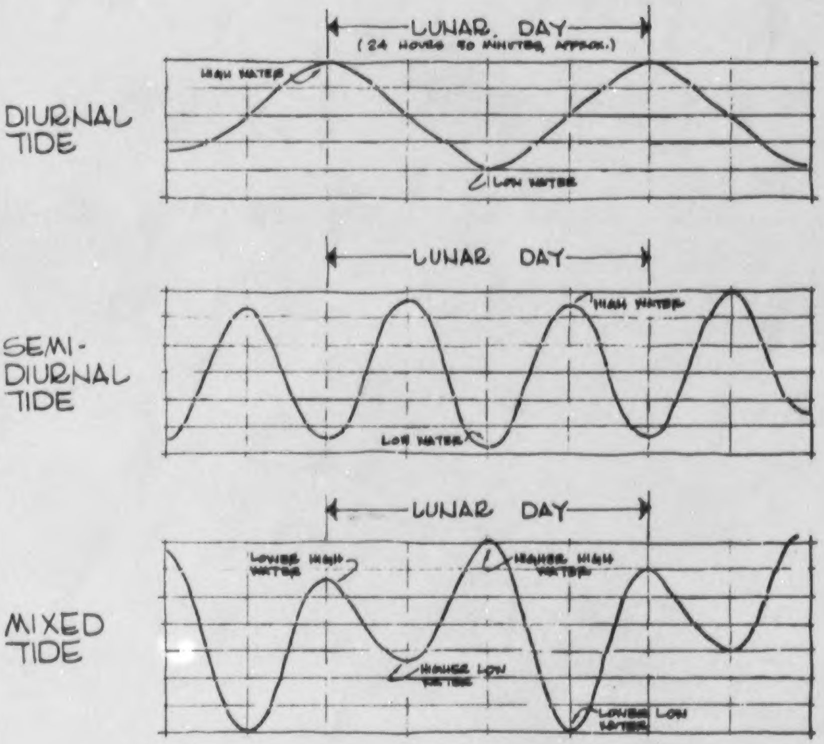

Figure 7.—*Examples of marigram types.*

In coastal areas where the water is shallow, wind interacts with water at the surface and as a result moves the water from one area to another. It is not easy to say exactly how a water body will respond because the effects are determined by wind speed, duration, and distance over which the wind blows (*fetch*), as well as by such other complicating factors as topography and stage of the tide.

It is generally true in coastal areas, however, that the water surface will respond directly to the wind. Thus, a wind blowing toward shore will tend to raise the water level on the coast and wind blowing away from shore, to decrease it.

As barometric pressure increases, the elevation of the surface of the water tends to be depressed and, conversely, as the pressure decreases, the elevation tends to be increased. As with wind, the amount of displacement is difficult to predict and depends on the intensity of the barometric disturbance and the speed with which it moves, in addition to the characteristics of the body of water.

The meteorological effects are particularly noticeable with the passage of large storms such as hurricanes. Strong winds and low pressure can raise the water level along a coast considerably. If this resultant storm surge is superimposed on an unusually high tide, occurring normally at that time, extreme flooding is often the result.

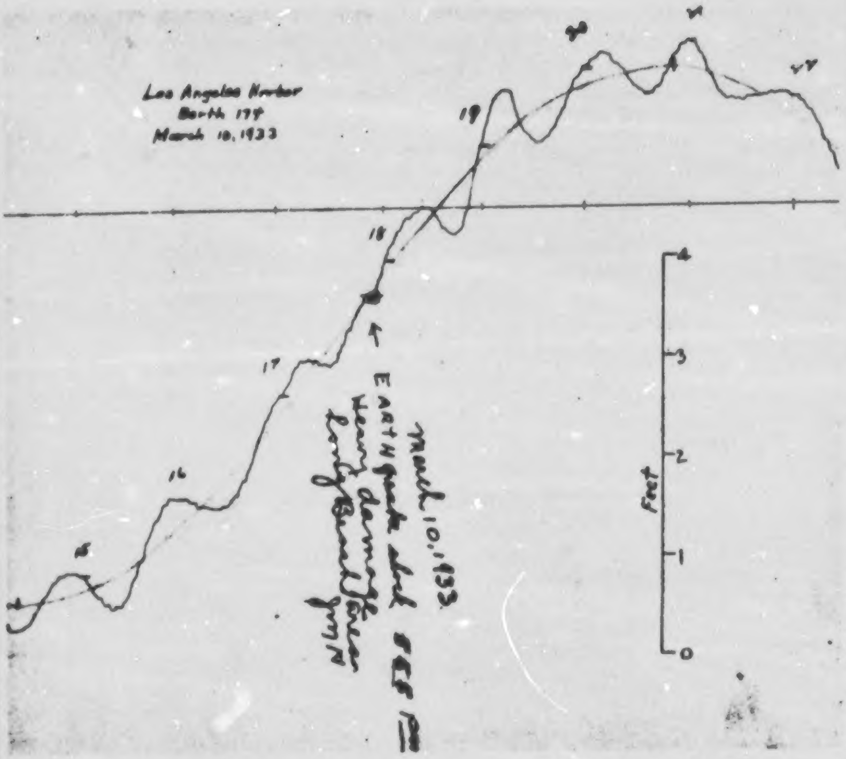

Figure 8.—*Part of the tide curve for March 10, 1933, at San Pedro, Cal. Note the small (approximately 15-centimeter) seiche having a period of about 1 hour. The Long Beach earthquake failed to materially disturb the seiche, although it shook the gauge. Courtesy C. K. Green, U.S. Coast and Geodetic Survey. Reprinted, by permission, from K. O. Emery,* The Sea Off Southern California *(New York: John Wiley and Sons, 1960).*

To some extent, the meteorological effects are predictable with change of seasons and can be estimated for predicting water level. Random disturbances raise havoc in predicting water level, however. If the astronomic tide is small, then random meteorological disturbances often represent a significant portion of the total change in water level—making accurate predictions extremely difficult.

Tide predictions generally do not include provisions for the contributions to the change in water level for other than the astronomic tide. In some cases, however, the seasonal fluctuations are included. Thus, when actual water level does not agree with predicted tide elevations, it is not the result of poor tide predictions, but rather the influence of random meteorological effects.

Seiches. A *seiche* (pronounced SAYsh) is a stationary wave oscillation the period of which depends on the dimensions of the local semienclosed body of water. You create a simple miniature seiche when you tilt a rectangular dishpan of water. The maximum change in water elevation occurs at the ends of the pan while no change in water level occurs in the middle. Figure 8 shows the oscillations of a seiche with a period of about an hour imposed on the tidal fluctuation at San Pedro, California.

A seiche is generated by an external force, often one of the same forces that generate a storm surge. After the force has been removed, the body of water responds by oscillating at its natural frequency.

As the period of the seiche approaches that of the tide, it is possible that the range of the tide can be considerably affected. Some of the great tidal ranges in the world can be attributed to this interaction of the tide of the open ocean and the seiche of a semienclosed body of water. For example, the mean range of tide at Burntcoat Head, which is in the Minas basin of the Bay of Fundy, is 11.69 meters.

Tidal currents. Oceanographers usually define *current* as a horizontal flow of water. A *tidal current* is a horizontal flow of water generated by the tide-producing forces .

Tidal currents, like the tides themselves, are periodic, and they can be analyzed and predicted. Tides, as one-dimensional phenomena, are easy to monitor. Tidal currents, on the other hand, are more complicated because they are two-dimensional (speed and direction). There are some cases, however, in which the movement of the waters is confined to one dimension, so the direction of flow reverses as the water flows alternately toward (*flood current*) and away from (*ebb current*) the land.

Oregon tides

Taking a look at tides along the Oregon coast offers an opportunity to apply our understanding of tidal phenomena.

What kind of tides does Oregon have? A look at the sample marigram for Newport, Oregon, in figure 9 reveals that there are two low waters and two high waters each day. In addition, there is an inequality both in the low waters and in the high waters. From this, we conclude that tides along Oregon are *mixed tides.*

The average difference in the elevation of the two low waters each day is 0.67 meter. The average difference in the elevation of the two high waters each day is only 0.43 meter. Thus, the low water inequality is about 1.5 times larger than the high water inequality for the Oregon coast.

What is the range of tides in Oregon? The range of tide varies along the coast, but it is generally less in the south. Table 1 shows tide ranges from 1.80 meters at Brighton and Yaquina Bay to 1.52 meters at Taft.

When do tides occur in Oregon? As a standard, the time of high water and low water for a given location is described in relation to the Moon's passage over the Greenwich (England) meridian. The time between the Moon's transit over the Greenwich meridian and the succeeding high or low water at a certain location is known as the *high water interval* or *low water interval.* Along the Oregon coast, these intervals generally increase from south to north, with the time of both high water and low water occurring about an hour sooner in the south than in the north.

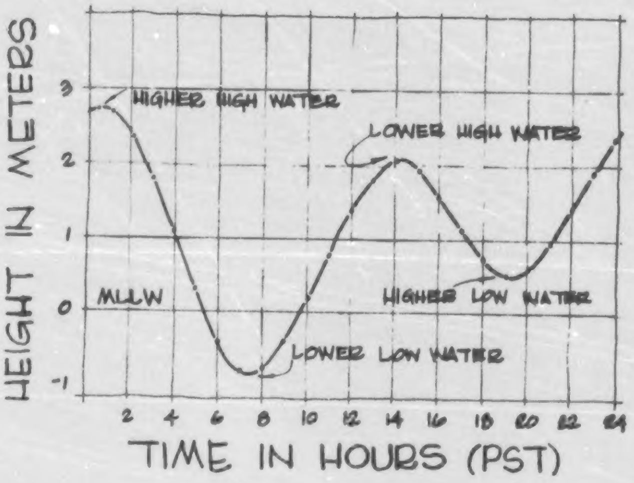

Figure 9.—*Marigram obtained at the pier of the Oregon State University Marine Science Center, Newport, May 13, 1964. Note the "clamming" tide in the morning.*

When do Oregon's highest and lowest tides occur? Each year, the largest diurnal inequality (see page 6 for review) occurs in June and July, and in December and January. These times are associated with solstices in June and December. (A solstice is either of the two times a year when the Sun is at its greatest distance from the equator: about June 21, when the Sun reaches its northernmost point on the celestial sphere, or about December 22, when it reaches its southernmost point.) Mean sea level, which varies annually because of the meteorological effects and runoff from winter rains and lower water temperatures, reaches its highest level in December on the Oregon coast.

As a consequence of the greater diurnal inequality and high sea level, the highest predicted tide usually occurs during December or January. Often winter storms further raise the water level above the normal winter high tides, resulting in local flooding.

Table 1.—*Mean range of tide at selected locations along the Oregon coast*

Location	Mean range (meters)
Columbia River entrance (N. jetty)	1.70
Brighton	1.80
Barview	1.74
Taft	1.52
Yaquina Bay entrance	1.80
Waldport	1.77
Umpqua River jetty	1.55
Coos Bay entrance	1.58
Bandon	1.58
Port Orford	1.61
Brookings	1.55

The lowest tides of the year generally occur in summer as a result of the increased inequality in the low waters combined with the lowered sea level.

Why are good clam tides in the evening in December and in the morning in June? This is a result of the concurrence of extreme astronomical phenomena:

In December
- —when there is a full Moon, resulting in spring tides,
- —the Moon is near north declination, increasing diurnal inequality.

In June
- —when there is a new Moon, resulting in spring tides,
- —the Moon is near north declination, increasing diurnal inequality.

The *times* of the lows are related to the passage of the Moon over the Oregon coast. Full Moon crosses overhead at midnight, while new Moon crosses overhead at noon. The difference in time between transit of the Moon over the Oregon coastal area and the following lower low water is about 18 hours (Low water interval, LWI, for Oregon referred to Greenwich meridian is about two hours. The Moon passed over Oregon's local meridian some 16 hours earlier, however; 16 hours plus 2 hours makes the difference, 18 hours.) Thus, the good clamming tides follow the transit of the full Moon in December by 18 hours, and occur at about 6 p.m., and in June by about 18 hours after the transit of the new Moon, or near 6 a.m.

How do tides vary in the estuaries? The time and range of tide in the estuaries vary considerably from the time and range of tide along the coast. Each estuary has its own individual characteristics. In the case of the Columbia River, the periodic tide can be detected up to Bonneville Dam. The tide progresses up the river so that the mean range decreases to only 0.3 meter at Ellsworth, Washington, 182 kilometers from the river's mouth. At Ellsworth, high water occurs about six hours after that at Astoria; low water, nearly eight hours after that at Astoria.

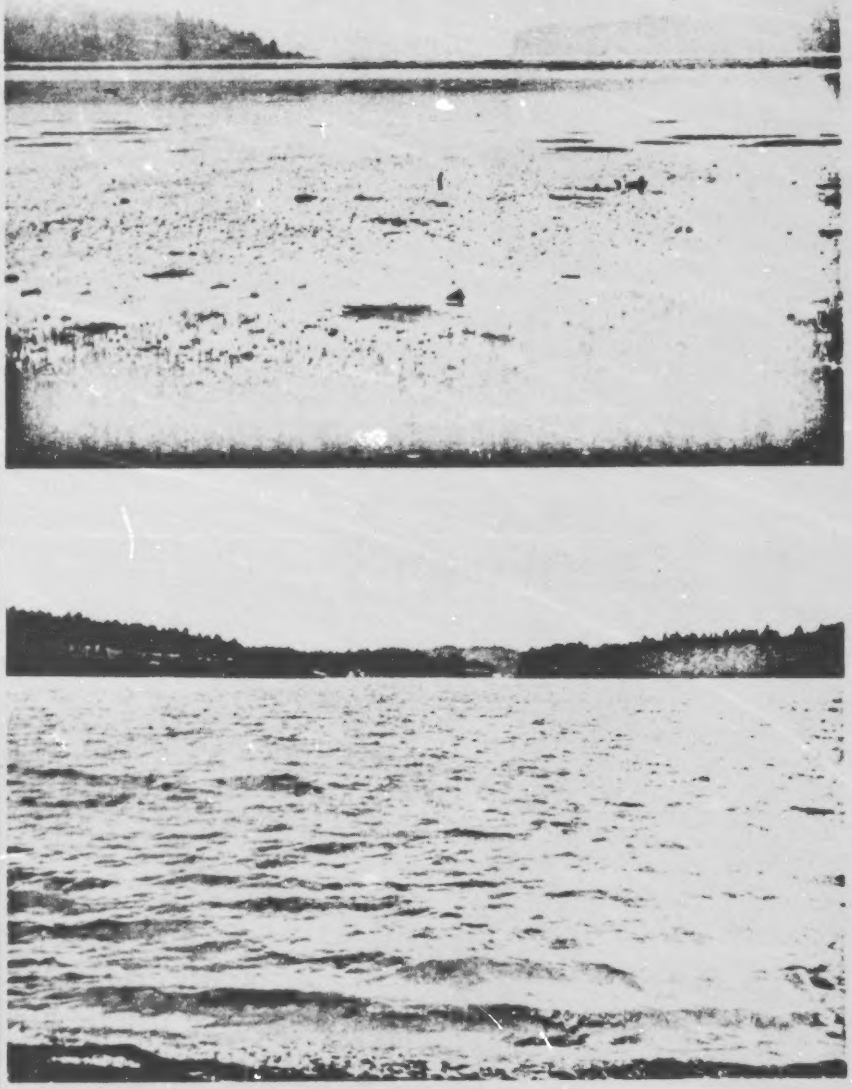

Figure 10.—*Below the high tide line, the land continues to slope downward. As tides rise and fall daily, the waters alternately advance and retreat across this sloping zone. Tidal effects reach well upstream on coastal rivers and streams. In many of the Pacific Northwest's coastal rivers, extreme low tides give recreationists access to beds of bay clams; therefore, these have come to be known as "clam tides." The advance and retreat of high and low tides in these views of Oregon's Yaquina River were photographed from the same place, seven hours apart on the same day.*

Want more information?

To obtain more information on tides, write to: Director, National Ocean Survey, 6001 Executive Blvd., Rockville, MD 20852.

Predictions of the times and heights of high and low water are prepared by the National Ocean Survey (National Oceanic and Atmospheric Administration) for a large number of stations in the United States and its possessions as well as in foreign countries and United Nations Trust Territories. These predictions are published each year (approximately six months or more in advance) in four volumes. The titles are: *Tide Tables—High and Low Water Predictions:* (1) East Coast of North and South America, Including Greenland; (2) Europe and West Coast of Africa, Including the Mediterranean Sea; (3) West Coast of North and South America, Including the Hawaiian Islands; and (4) Central and Western Pacific Ocean, and the Indian Ocean. They are available from local Nautical Chart Agencies at a nominal price.

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Glossary

Aphelion—The point in the Earth's orbit farthest from the Sun.

Apogee—The point in the Moon's orbit farthest from the Earth.

Current—A horizontal movement of the water. Currents may be classified as tidal and nontidal. *Tidal currents* are caused by the tide-producing forces of the Moon and the Sun and are a part of the same general movement of the sea that is manifested in the vertical rise and fall of the tides. *Nontidal currents* include the permanent currents in the general circulatory systems of the sea as well as temporary currents arising from meteorological conditions.

Declination—The angular distance of a celestial body north or south of the celestial equator.

Diurnal inequality—The difference in height of the two high waters or of the two low waters each day.

Diurnal tide—A tide having only one high water and one low water during a lunar day of 24 hours and 50 minutes.

Equatorial tides—Tides occurring semimonthly as the result of the Moon being over the equator. At these times the tendency of the Moon to produce a diurnal inequality in the tide is at a minimum.

Equilibrium theory—A hypothesis under which it is assumed that the waters covering the face of the Earth instantly respond to the tide-producing forces of the Moon and the Sun and form a surface of equilibrium under the action of these forces. The theory disregards friction and inertia and the irregular distribution of the land masses of the Earth. The theoretical tide formed under these conditions is known as the *equilibrium tide*.

High water interval (HWI)—The time interval between the Moon's transit (upper or lower) over the local or Greenwich meridian and the following high water at a specific location.

Low water interval (LWI)—The time interval between the Moon's transit (upper or lower) over the local or Greenwich meridian and the following low water at a specific location.

Marigram—A graphic record of the rise and fall of the tide. The record is in the form of a curve in which time is represented by abscissas and the height of the tide by ordinates.

Mean high water (MHW)—The average height of the high waters over a 19-year period.

Mean higher high water (MHHW)—The average height of the higher high waters over a 19-year period.

Mean low water (MLW)—The average height of the low waters over a 19-year period.

Mean lower low water (MLLW)—The average height of the lower low waters over a 19-year period.

Mean sea level (MSL)—The average height of the surface of the sea for all stages of the tide over a 19-year period, usually determined from hourly height readings.

Mixed tide—Type of tide in which the presence of a diurnal wave is conspicuous by a large inequality in either the high or low water heights, with two high waters and two low waters usually occurring each lunar day.

Meteorological effects—Fluctuations in water level having their origin in the daily or seasonal variations in weather conditions, which may occur with some degree of periodicity.

Neap tides—Tides of decreased range occurring semimonthly as the result of the Moon being in quadrature.

Perigee—The point in the orbit of the Moon which is nearest the Earth.

Perihelion—The point in the orbit of the Earth nearest the Sun.

Quadrature of Moon—Position of the Moon when its longitude differs by 90° from the longitude of the Sun. The corresponding phases are known as first quarter and last quarter.

Range of tide—The difference in height between consecutive high and low waters. The *mean range* is the difference in height between mean high water and mean low water. The *great diurnal range* or *diurnal range* is the difference in height between mean higher high water and mean lower low water. Where the type of tide is diurnal, the *mean range* is the same as the *diurnal range*.

Seiche—A stationary wave oscillation with a period varying from a few minutes to an hour or more, but somewhat less than the tidal periods. They are usually attributed to strong winds or changes in barometric pressure and are found both in enclosed bodies of water and superimposed upon the tide waves of the open ocean.

Semidiurnal tide—A tide having two high waters and two low waters in a lunar day. The elevations of succeeding high waters and succeeding low waters are nearly equal.

Spring tides—Tides of increased range occurring semimonthly as the result of the Moon being new or full.

Storm surge—See *meteorological effects*.

Tidal current—See *current*.

Tidal datum—A base elevation defined by a certain phase of the tide, used as a reference from which to reckon heights or depths.

Tidal epoch—The 19-year period over which the various phases of the tide are averaged in order to determine a tidal datum.

Tropic tides—Tides occurring semimonthly when the effect of the Moon's maximum declination is greatest. At these times there is a tendency for an increase in the diurnal range.

Appendix.—*Metric/English conversion factors (approximate) for the units cited in this bulletin*

To convert	to	multiply by
meters	feet	3.28
feet	meters	0.30
centimeters	inches	0.39
inches	centimeters	2.54

OREGON STATE UNIVERSITY
EXTENSION
SERVICE

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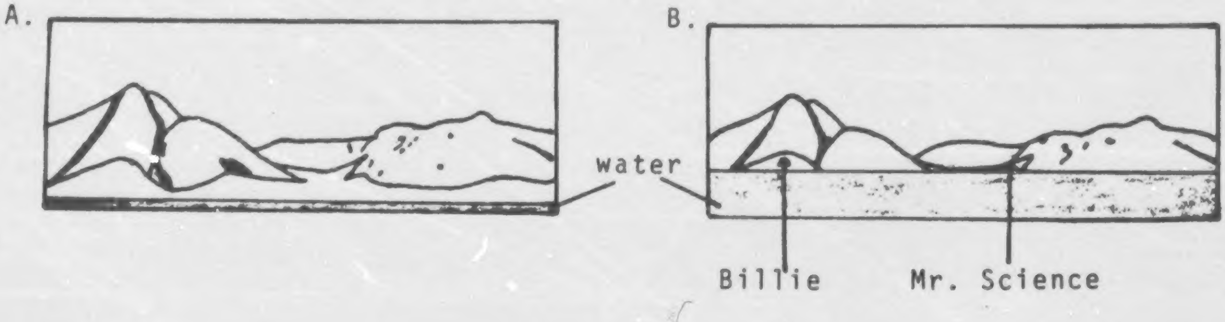
6-77/5M

OCEANS IN MOTION: Tides

Rise and Fall

Mr. Science took his class to the seashore to study. Part of the assignment was to find as many different kinds of living things as possible. Billie Bright took off, determined to win the prize for finding the most living things. He walked down the beach and around a rocky bank that jutted out into the beach. He was finding lots of plants and animals. After a couple of hours Billie decided to return to the starting spot and show Mr. Science all of the neat critters he had found. Billie walked back along the beach. To his surprise the rocky point was now covered with water to a depth of about three feet. He was stuck! He couldn't go forward because of the rocks. Will Billie have to spend the rest of his days on the beach? Can Mr. Science explain what happened?



What caused the rapid movement of water onto the beach? Could Billie have predicted that the water was going to rise?

Billie's problem stems from the fact that when he walked past the rocks, the water level was at its low point or low ebb. When Billie started to walk back, the water was rising or flooding. We call this rise and fall of ocean water the tide.

History

From ancient times, people who lived along the ocean shores have watched the rise and fall of the tides. The regular rhythm of the rising and falling was said to represent the breathing of the earth. People noticed that there were two high tides (the peak of the flooding stage) and two low tides (the low point of the ebb) every day. By watching the tides for long periods of time and recording the heights, man was able to predict the tides. Billie would have benefitted from knowledge of these predictions.

1. What is the tide?

What else did people notice about the rising and falling of the tides? From their records they soon discovered that there were two especially high tides and two especially low tides every 29 days. Not only were the changes regular, they also followed the changes seen in the phases, or light and dark patterns, of the moon. People began to wonder "Did the moon cause the tides?"

2. People who lived along the coasts noticed several things about the tides. List four of their observations.

   a.

   b.

   c.

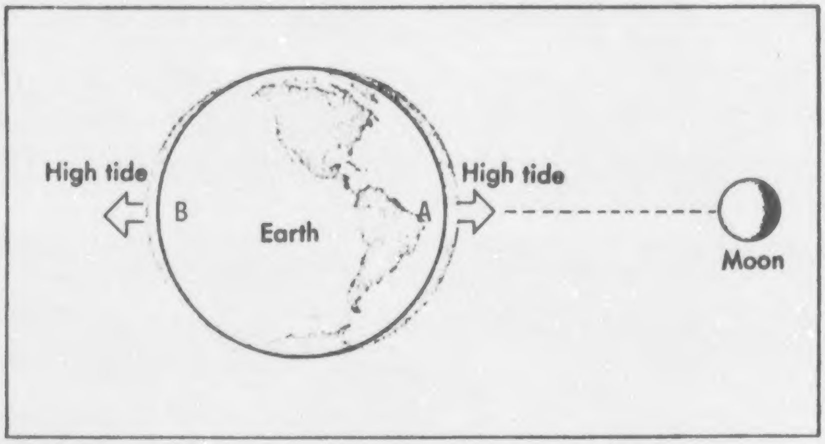
   d.

What Causes the Tides?

About 1700, Sir Isaac Newton gave us the theory that would eventually explain the tides. In what has since come to be known as the Law of Gravity, Newton stated that everything (large or small,) in the universe, exerts a pull on everything else. How does this help explain the tides?

The heavier and the closer the object, the greater the force of attraction. The moon's gravitational pull tends to create a bulge in the ocean under the moon. This bulge is shown in figure 1 at point A. The earth is also rotating about its axis. This rotation tries to throw the waters in the oceans away from their basin. The centrifugal force of rotation creates a second bulge in the ocean on the opposite side of the world from the bulge caused by the moon's attraction. This bulge is shown in figure 1 at point B.

Fig 1



3. What causes the two bulges seen in figure 1?

The moon rises later each day. It takes a point on the earth about 52 additional minutes each day to catch up with and pass through the moon's two tidal bulges. As a result, every 24 hours and 52 minutes there are two high tides and two low tides. The tides are about 52 minutes later each day. Keep in mind that in the real world, there are no simple tidal bulges.

4. Why do high tides come 52 minutes later each day?

The Sun Also Plays a Role

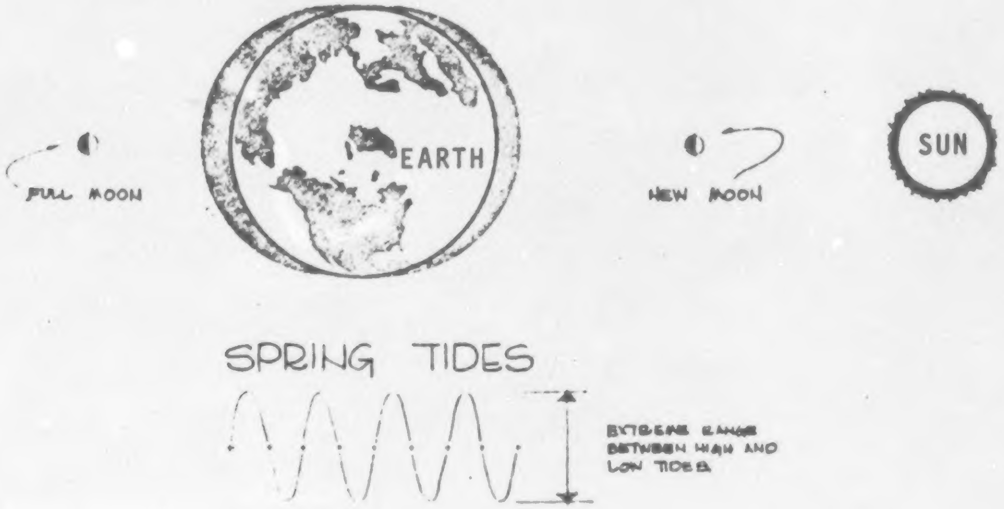
Although the sun is much farther away than the moon, its much greater mass allows it to play a role in the tides. The sun's gravitational pull also tends to create two tidal bulges. One is under the sun and the other is on the opposite side of the world. These bulges are smaller than those caused by the moon and ordinarily do not have a separate effect. Instead, they increase or decrease the moon's tide.

Let's look at the sun's effect. The difference between successive high and low tides is called the tidal range. The tidal range changes as a result of the changing positions of the sun and the moon with respect to the earth. As the moon rotates around the earth about once a month, it is in line with the sun twice a month and it is at right angles at two other times during the month.

5. If the high tide Monday is 9.7 feet and the low tide is 0.3 feet, What is the tidal range for Monday?

When the moon and sun are in line, the attractive forces are added together and the tide rises higher and falls lower than the average. The tidal range is at the maximum. These tides are called spring tides. The name refers to the springiness of the water and not to the time of the year. Figure 2 shows spring tides.

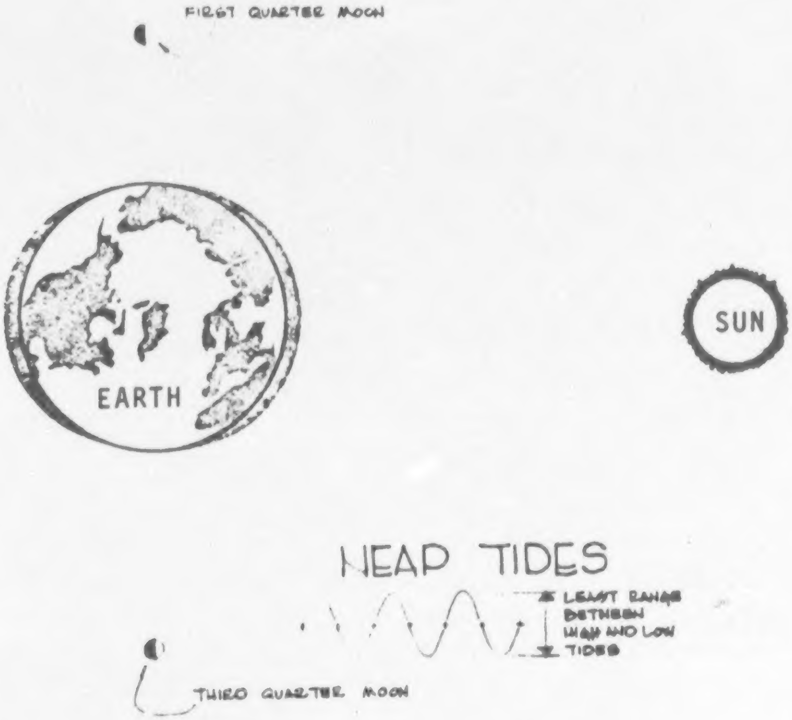
Figure 2


FULL MOON
EARTH
NEW MOON
SUN
SPRING TIDES
EXTREME RANGE BETWEEN HIGH AND LOW TIDES

6. What causes the spring tide?

When the moon and the sun are at right angles with respect to the earth, the attractive forces of the sun and the moon work against each other. At this time the tidal range is decreased. The tide rises and falls less than the average. We call these tides neap tides. Figure 3 shows neap tides.

Figure 3


FIRST QUARTER MOON
EARTH
SUN
NEAP TIDES
LEAST RANGE BETWEEN HIGH AND LOW TIDES
THIRD QUARTER MOON

7. What causes the neap tide?

REAL Life

From what we have seen, there should be two high tides and two low tides in every place about every twenty four hours. Yet if we look around we find places with only one high and one low tide a day. We find other places that sometimes have two high and two low tides a day and at other times have one high and one low. We also see great variations in the height and duration of the tides. Why?

Scientists have discovered that the distribution of the oceans and land masses is irregular. This irregularity causes the oceanic basins of the world to respond to tide producing forces as individual closed basins. In spite of the fact that all of the oceans are connected, the oceans do not behave as a unified whole. Each ocean independently feels the effect of the moon and sun. In each of the natural basins, the water sloshes back and forth at a speed determined by the length and depth of the basin.

8. What causes variation we see in real life tides?

The Importance of Tides

How are tides important to us? Billie Bright would have at least one answer for you. Ships and boats watch the tides to avoid running aground entering and leaving shallow harbors. Fishermen watch the tides. The incoming tides bring new food supplies and the fishing is best on an incoming tide. People who gather shellfish watch for low tides. Tides are important in the lives of people. They are also important in the lives of all the seashore animals and plants that live on the shoreline.

9. From your reading what do you think the terms "tideland" and "tide pool" mean?

ONE STEP FURTHER...............

1. We have seen that both the sun and the moon have an effect on the tides. Can we calculate the importance of each? Let's look at the tide producing forces of two imaginary suns, star A and star B.

   a. The tide producing force of a heavenly body varies directly with its mass. In other words, star A which has twice the mass of star B would have twice the tide producing force. The sun has a mass 27,000,000 times greater than the moon. As far as mass is concerned, how many times greater is the tide producing force of the sun compared to that of the moon?

   b. The tide producing force of a heavenly body also varies inversely with the cube of the distance to the earth. For example, if star A were twice as far from the earth as star B, its tide producing force would be $\frac{1}{2}^3$ or ($\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = 1/8$) or one eighth of the tide producing force of star B.

      The sun is 389 times farther away from the earth than the moon. As far as distance is concerned, how many times less is the tide producing force of the sun compared to that of the moon? Show your work!

   c. The tide producing force of a body is actually a combination of the forces due to mass and distance. For example, star A would have twice the force from mass times one eighth the force from distance

      Star A = $(2 \times 1/8) = 1/4$ Star A then has one fourth the tide producing power of Star B.

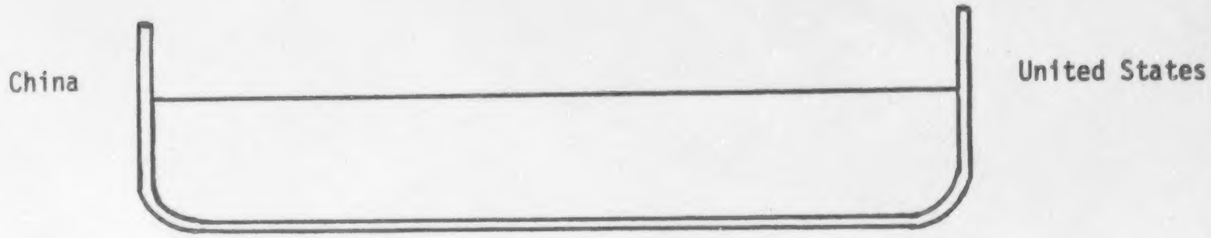
      Combine the forces due to mass and distance to calculate what the tide producing force of the sun is compared to the tide producing force of the moon. Show your work!

   d. How much less is the sun's tide generating force?

   e. Which heavenly body is most responsible for the tides?

MORE, ONE STEP FURTHER.........

We have seen that the irregularity in the distribution of the oceans and land masses causes the oceans to respond to the tide producing forces independently. The water in each basin sloshes back and forth at a rate of speed determined by the length and depth of the basin. Let's let the tank in figure 1 represent an ocean basin.



1. Use your imagination to tilt the ocean basin toward the United States. (Careful! Don't let the water run out). Draw a line that would show the new water surface. LABEL this line AB by writing an A at the China end and a B at the U.S. end.
2. Use an N to LABEL the point where line AB crosses the original water surface.

   Line AB represents a stationary wave. In the real oceans, water moves in stationary waves. The Tide-making forces of the moon and sun keep the waves moving.

   a. If AB represents the new water surface, which country is having a high tide?
   b. High tides would be occurring all the way from B to ________.
   c. Which country is having a low tide? ____________________
   d. Low tides would be occurring all the way from A to ________.
   e. What happens to the water level at N?

3. Use your imagination to now tilt the ocean basin the same amount but in the opposite direction. Draw a second line through N that would show the new water surface. LABEL this line CD with C at the China end of your ocean basin.

   a. If CD represents the new water surface, which country is having a high tide?

   b. High tides would be occurring all the way from __________ to ______________.

   c. Which country is having a low tide?

   d. Low tides would be occurring all the way from ___________ to ______________.

   e. What happens to the water level at N?

N represents a nodal line. Any island located along line N would have very small tides since the water level at N remains the same whether it is high tide on the China coast or on the coast of the United States. For example, Tahiti is near a nodal line in the Pacific Ocean. The tides on Tahiti are small and are due to the sun's pull alone.

4. What is a nodal line?

TEACHER BACKGROUND - Using the 24 Hour Clock

It is especially important that the students be thoroughly trained and practiced in the use of military time or the 24-hour time system before instruction in the use of the Tide Tables is given. Just as the use of the metric system should be employed, so should the 24 hour clock be used in the classroom laboratory and in the field.

Less than one laboratory period (50 min.) is required for this exercise. Discussion should be encouraged.

The exercises given here lend themselves to many variations. Answers given are for convenience (see Conclusions for the teacher.)

Keep in mind that standard time based upon time meridians is used, almost without exception, in published tables and reports. Therefore, local variations such as "summer time" or "daylight saving time" must be acknowledged.

The classroom clock can be converted by numbering the extra hours, 13 through 24, either to the clock face or around its outer edge. If finances permit, a bona fide 24-hour wall clock can be purchased.

Answers to Exercise A:

1. 0752 hrs.
2. 1952 hrs.
3. 1000 hrs.
4. 2200 hrs.
5. 1530 hrs.
6. 1715 hrs.
7. 1200 hrs.
8. 2400 hrs. or 0000 hrs. (next day)
9. 0004 hrs.

Answers to Exercise B:

1.	Addition	2.	Subtraction
(a)	0400 hrs.	(a)	1308
(b)	0308 hrs. (next day)	(b)	0752
(c)	0010 hrs. (next day)	(c)	0144
(d)	1330 hrs.	(d)	2220 (day Before)

KEY WORDS

Greenwich Mean Time
hundred hours
time
Universal Time

USING THE 24 HOUR CLOCK

Time is defined as a measurable period during which an action exists. The manner in which time is expressed must then, suit the purpose for which it is intended. There are many reasons for a 24-hour clock. Accuracy, not only in recording, but also in communicating, is a primary argument for the 24-hour clock. The terms "AM" and "PM" are not required. For instance, 2400 hours of June 10 is the same as 0000 hour June 11. Daytime and nighttime are not significant factors. There are many places on the earth that are without the sun's light for weeks at a time. At other times there are no nights. Time in a "Sea Lab" or other underwater stations would have little use for the "AM" and "PM" designations. The day begins at midnight and runs for 24 hours.

The 24-hour clock can be adapted to Greenwich Mean Time (GMT) or Universal Time (UT) for world-wide usage. The U.S. Department of Commerce Tide Tables uses the 24-hour clock exclusively, as do many navigational tables and charts.

Use the 24-hour clock when asked, "What time is it?" In written work, at least in the field of marine science, record all times in 24-hour designations.

In this exercise you will learn how to express time and how to compute time differences using the 24 hour clock.

Materials:

wall clock. (modifications optional)

pencil (with eraser)

Procedure:

A. Conversion to 24-hour Time.

Orally, 24-hour time is expressed in "hundreds": for instance 8:00 AM would be spoken "eight hundred hours"; 2:30 PM would be spoken "fourteen-thirty hours".

The written time uses four digits. Convert the following to the 24 hour clock.

AM-PM CLOCK	24-HOUR CLOCK
1. 7:52 AM	______________
2. 7:52 PM	______________
3. 10:00 AM	______________
4. 10:00 PM	______________
5. 3:30 PM	______________
6. 5:15 PM	______________
7. 12:00 noon	______________
8. 12:00 midnight	______________
9. 12:04 AM	______________

B. Computing Time Differences

Keep in mind that the first two digits, reading from left to right, of a time expression represent hour, and that the last two digits refer to minutes. Minutes amounting to 60 or more must be converted to hours. If subtracting minutes, and "borrowing" becomes necessary, remember that when you "borrow" from the hour digit you are borrowing sixty minutes not one hundred minutes!

1. ADDITION

(a) 0240 hrs.
+0120 hrs.

(b) 1708 hrs.
+1000 hrs.

(c) 2250 hrs.
+0120 hrs.

(d) 1100 hrs.
+0230 hrs.

1. SUBTRACTION

(a) 1358 hrs.
-0050 hrs.

(b) 0911 hrs.
-0119 hrs.

(c) 0234 hrs.
-0050 hrs.

(d) 0120 hrs.
-0300 hrs.

TEACHER BACKGROUND - Tide Tables

The pages from the National Ocean Survey tide tables necessary for completion of the activity "Tide Tables" are included in the student section. Complete editions of the Tide Tables can be purchased for about $2.00 and will provide instruction for several years. It is not necessary to have the latest edition of the Tide Tables in order to learn the procedure.

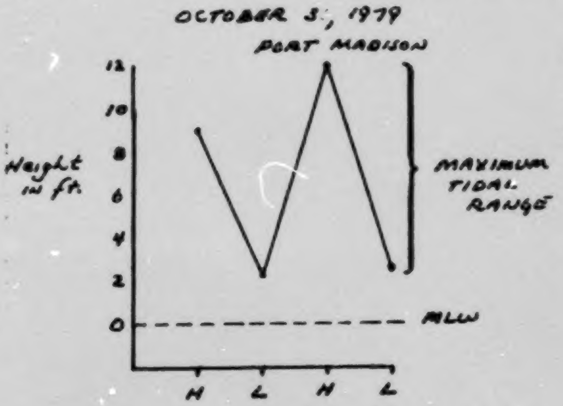
Even though adequate instructions are given in Tide Tables, the student will find these exercises an aid to learning. You will find it helpful to devise additional exercises for student practice. The exercises that follow involve: (1) finding the times of high and low tides; and (2) finding the range of daily tides.

A minimum of two class days should be allotted for instruction. With these procedures available to the student, practice in the use of Tide Tables can be extended through home study. Exercises, A through D should be done in sequence. The activity, "The 24-Hour Clock", should precede instruction in the use of the Tide Tables.

KEY Exercise D

	High		Low		High		Low	
	Time	Height	Time	Height	Time	Height	Time	Heigh
Seattle	0240 hrs	1.1 ft	0945 hrs	12.9 ft	1618 hrs	4.1 ft	2141 hrs	8.5 f
Correction	+031	+3.1	+046	+0.2	+031	+3.1	+046	+0.2
	-311 hrs	4.2 ft	1031 hrs	13.1 ft	1649 hrs	7.2 ft	2227 hrs	8.7 f

Graphic representation of maximum tidal range:



From the graph, the following ranges may be determined:

The maximum tidal range is 9.4 ft. (i.e., 12.0 ft. - 2.6 ft. = 9.4 ft.);
The minimum tidal range is 6.9 ft. (i.e., 9.0 ft. - 2.1 ft. = 6.9 ft.).

Questions:

1. The irregularity in the shape and distribution of the land masses and the oceans causes the tides to be different in different places. The times of the tides differ because the length of the lunar day is 24 hours and 52 minutes, causing the tides to be about 52 minutes longer each day.
2. Yes, local hazards usually are considered to be shallow bottoms, which can be a shipping hazard during low tides. Tides can greatly influence the ease with which ships can enter or leave ports. Depth of water is not the only hazard. For example, the aircraft carrier U.S.S. Enterprise can only pass under the Golden Gate Bridge to enter San Francisco Bay on a low tide. In this case, the height of the tide is the important consideration.
3. This information allows the pilot to determine how much water is under his vessel as he enters or leaves port.
4. The clearances are given in feet above Mean High Water, since the boater is interested in whether his vessel will fit under the bridge at high tide. Presumably, if he can fit under at high tide, he can also fit under at low tide! Mean High Water is a safer datum to use for referencing vertical clearance.
5. The tides differ in time because of the shape of the Puget Sound, which restricts the flow of the waters.
6. Yes, D-Day in World War II, for instance, was largely determined by available tides. High tides minimized the amount of open beach troops had to run across to make their landing.
7. One bulge is due to the gravitational attraction of the moon, while the second is due to the centrifugal force due to the rotation of the earth.
8. This question is a prelude to many activities which will follow. The ways organisms cope with the intertidal environment are legion: some move with the water level changes, others capture water inside for the drying period, others close up shop for the low tide period. Encourage discussion, but recall that these adaptations will receive more attention later on.

9. When the moon and sun are in a straight line with respect to the earth we experience spring tides. When the moon and sun are at right angles to each other with respect to the earth we have neap tides.

KEY WORDS

- celestial
- diurnal
- high tide
- intertidal zone
- littoral
- low tide
- maximum tidal range
- Mean Lower Low Water
- minimum tidal range
- navigable
- neap tides
- reckon
- seiche
- semi-diurnal
- spring tides
- tidal bore
- tide
- tsunamis

REFERENCE:

Tide Tables, 1979. High and Low Water Predictions. West coast of North and South America, including the Hawaiian Islands. Department of Commerce. National Oceanic and Atmospheric Administration, National Ocean Survey. U.S. Government Printing Office: Washington, D.C.

TIDE TABLES

The tide is a giant wave thousands of miles long! Twice a day most of the oceans' shorelines are alternately covered with water then exposed to the sun. Change in water height from the tides may vary from a few tenths of a foot in some areas to over twenty feet in other areas. In the Bay of Fundy alone, some 100 billion tons of water are moved in and out with each tide. As a comparison the Mississippi River would take nearly 140 days to move as much water as the daily flow of water in the Bay of Fundy.

Knowledge of tidal movement is important to marine science. Accurate predictions of tidal times and heights are as essential to the field ecologist as to the pilot of a marine research vessel. The marine biologist is aware that animals of the intertidal zone have definite tidal behavior patterns. Greater ranges between high tide and low tide mean that animals living along the ocean edge must adapt to long periods of submergence and exposure.

The average time between high tides is 12 hours and 25 minutes. Predictions of tide times and heights are made by a combination of local harbor records and astronomical information. Local records are obtained from tide guages placed in quiet waters not exposed to surface action. These predictions are published, each year, as the Tide Tables. It is important to note that due to the changes in tides caused by local weather, tide tables are seldom completely accurate. The following exercises will help you learn how to use tide tables to predict the times and heights of high and low water. Do the exercises in sequence by following along with a copy of the Tide Tables. Work out each computation. After you feel comfortable using the tables, pick a place and a date, at random, and determine the times and heights of the high and low tides. Compare your findings with the answers found by other students in your class.

Procedure:

Exercise A - High and Low Tides for Mystery Bay

Find the times of high and low tides for Mystery Bay, Washington, for November 29, 1979.

Step 1. The index to Table 2 of the Tide Tables 1979, states that Mystery Bay, Washington, is Number 900. Turn to Table 2 on page 177. Find Number 900, "Mystery Bay, Marrowstone Island."

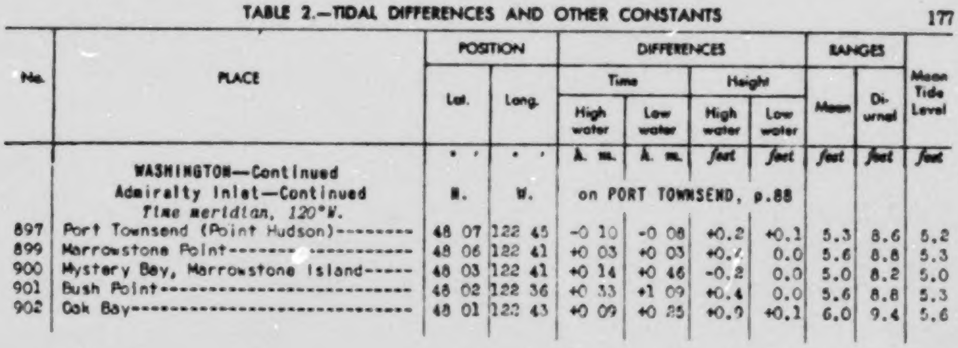


TABLE 2.—TIDAL DIFFERENCES AND OTHER CONSTANTS 177

No.	PLACE	POSITION		DIFFERENCES				RANGES		Mean Tide Level
				Time		Height				
		Lat.	Long.	High water	Low water	High water	Low water	Mean	Diurnal	
		° ′	° ′	h. m.	h. m.	feet	feet	feet	feet	feet
	WASHINGTON—Continued Admiralty Inlet—Continued *Time meridian, 120°W.*	N.	W.	on PORT TOWNSEND, p.88						
897	Port Townsend (Point Hudson)--------	48 07	122 45	-0 10	-0 08	+0.2	+0.1	5.3	8.6	5.2
899	Marrowstone Point-------------------	48 06	122 41	+0 03	+0 03	+0.4	0.0	5.6	8.8	5.3
900	Mystery Bay, Marrowstone Island-----	48 03	122 41	+0 14	+0 46	-0.2	0.0	5.0	8.2	5.0
901	Bush Point--------------------------	48 02	122 36	+0 33	+1 09	+0.4	0.0	5.6	8.8	5.3
902	Oak Bay-----------------------------	48 01	122 43	+0 09	+0 25	+0.9	+0.1	6.0	9.4	5.6

Step 2. Read across to under "Differences, Time." The high water time difference reads: plus (+) 0 hours 14 minutes. The low water difference reads: plus (+) 0 hours 46 minutes on Port Townsend (the reference station). This means that high tides occur at Mystery Bay 14 minutes after they do in Port Townsend and the lows occur 46 minutes after they do in Port Townsend. Now refer to the Port Townsend Times and Heights of High and Low Waters (Table 1). These begin on page 88 for the calendar year 1979.

Step 3. Page 91 from Table 1 is reproduced on the next page. Use this table and, under November, find "29th." The "TH" stands for Thursday. There are two highs and two lows for the day. A glance at the heights will show that the first tide, at 0025 hrs., is a high (6.1 ft.) and that the next, at 0518 hrs., is a low (3.3 ft.). Notice that the tables use the 24 hour clock.

PORT TOWNSEND, WASHINGTON, 1979

TIMES AND HEIGHTS OF HIGH AND LOW WATERS

OCTOBER						NOVEMBER						DECEMBER					
DAY	TIME h.m.	HT. ft.	DAY	TIME h.m.	HT. ft.	DAY	TIME h.m.	HT. ft.	DAY	TIME h.m.	HT. ft.	DAY	TIME h.m.	HT. ft.	DAY	TIME h.m.	HT. ft.
1	0524	0.3	16	0041	5.8	1	0132	6.8	16	0243	6.4	1	0301	7.7	16	0337	7.3
M	1330	8.0	TU	0630	2.1	TH	0656	2.3	F	0719	4.2	SA	0727	5.0	SU	0731	6.0
	1842	5.1		1357	7.9		1349	8.8		1337	8.0		1336	9.1		1303	8.4
	2351	6.8		1957	3.3		1956	1.5		2019	0.9		2020	-0.6		2012	-0.4
2	0627	0.3	17	0144	6.1	2	0240	7.5	17	0332	7.0	2	0357	8.4	17	0415	8.0
TU	1406	8.2	W	0719	2.3	F	0749	2.9	SA	0805	4.6	SU	0825	5.6	M	0821	6.4
	1924	4.2		1423	7.8		1423	8.8		1402	8.0		1414	9.0		1335	8.4
				2023	2.6		2036	0.3		2044	0.1		2059	-1.3		2044	-1.1
3	0110	7.2	18	0237	6.4	3	0342	8.1	18	0414	7.5	3	0449	9.0	18	0451	8.5
W	0722	0.5	TH	0801	2.6	SA	0842	3.6	SU	0849	5.1	M	0921	6.0	TU	0906	6.6
	1441	8.4		1444	7.7		1500	8.8		1427	8.0		1450	8.7		1407	8.4
	2009	3.1		2047	1.9		2118	-0.6		2112	-0.6		2137	-1.7		2119	-1.7
4	0221	7.6	19	0324	6.7	4	0438	8.5	19	0456	7.9	4	0535	9.3	19	0529	8.9
TH	0814	0.8	F	0839	3.0	SU	0933	4.3	M	0928	5.5	TU	1014	6.2	W	0949	6.7
	1514	8.5		1506	7.6		1532	8.6		1456	7.9		1522	8.4		1445	8.4
	2051	[illegible].9		2113	1.2		2156	-1.3		2141	-1.2		2215	-1.8		2156	-2.0
5	0324	8.0	20	0409	7.1	5	0533	8.8	20	0535	8.3	5	0623	9.4	20	0605	9.3
F	0903	1.4	SA	0915	3.4	M	1025	4.9	TU	1009	5.8	W	1109	6.3	TH	1036	6.7
	1549	8.6		1530	7.6		1607	8.4		1524	7.9		1558	7.9		1524	8.2
	2135	0.9		2141	0.5		2238	-1.5		2218	-1.6		2254	-1.6		2237	-2.1
6	0426	8.2	21	0451	7.3	6	0625	9.0	21	0620	8.6	6	0706	9.4	21	0643	9.5
SA	0949	2.1	SU	0953	3.8	TU	1118	5.4	W	1055	6.1	TH	1210	6.3	F	1128	6.6
	1622	8.6		1555	7.5		1639	8.0		1553	7.8		1636	7.4		1613	8.0
	2218	0.5		2210	-0.1		2320	-1.5		2255	-1.8		2335	-1.1		2319	-1.9
7	0522	8.4	22	0533	7.6	7	0718	9.0	22	0706	8.9	7	0748	9.3	22	0722	9.7
SU	1039	2.9	M	1032	4.3	W	1221	5.7	TH	1141	6.4	F	1319	6.1	SA	1227	6.3
	1656	8.4		1617	7.5		1718	7.5		1625	7.6		1717	6.9		1708	7.6
	2303	-0.5		2242	-0.5					2335	-1.7						
8	0621	8.4	23	0619	7.8	8	0002	-1.1	23	0748	9.0	8	0014	-0.5	23	0005	-1.3
M	1130	3.7	TU	1107	4.9	TH	0810	8.9	F	1241	6.5	SA	0830	9.2	SU	0806	9.7
	1732	8.2		1645	7.4		1335	5.9		1700	7.3		1435	5.8		1336	5.8
	2350	-0.7		2320	-0.8		1756	6.9					1803	6.3		1811	7.1
9	0722	8.3	24	0708	7.9	9	0047	-0.5	24	0020	-1.3	9	0058	0.3	24	0051	-0.4
TU	1225	4.5	W	1152	5.4	F	0905	8.7	SA	0836	9.1	SU	0909	9.0	M	0846	9.8
	1810	7.8		1711	7.3		1504	5.7		1358	6.4		1548	5.2		1445	5.1
				2359	-0.9		1842	6.3		1756	6.9		1905	5.7		1927	6.4
10	0037	-0.6	25	0800	8.0	10	0135	0.3	25	0112	-0.7	10	0142	1.2	25	0142	0.8
W	0825	8.1	TH	1245	5.9	SA	0958	8.6	SU	0925	9.2	M	0947	8.8	TU	0930	9.8
	1335	5.1		1739	7.1		1634	5.3		1527	5.9		1647	4.6		1557	4.1
	1849	7.3					1941	5.7		1912	6.4		2024	5.2		2103	5.9
11	0127	-0.2	26	0043	-0.7	11	0230	1.1	26	0205	0.2	11	0233	2.2	26	0241	2.1
TH	0934	8.0	F	0859	8.1	SU	1050	8.5	M	1015	9.2	TU	1024	8.7	W	1011	9.7
	1459	5.5		1357	6.2		1736	4.7		1639	5.1		1732	3.8		1700	3.0
	1935	6.7		1821	6.9		2103	5.3		2049	5.9		2211	4.9		2255	5.9
12	0225	0.4	27	0135	-0.4	12	0330	1.8	27	0308	1.2	12	0329	3.1	27	0344	3.5
F	1044	8.0	SA	0958	8.2	M	1136	8.4	TU	1100	9.3	W	1059	8.6	TH	1053	9.6
	1634	5.4		1533	6.2		1825	4.0		1732	4.0		1811	3.0		1752	1.8
	2033	6.2		1917	6.5		2246	5.1		2241	5.8						
13	0326	0.9	28	0233	0.1	13	0435	2.5	28	0413	2.3	13	0009	5.2	28	0045	6.4
SA	1149	8.0	SU	1100	8.4	TU	1212	8.3	W	1143	9.3	TH	0434	4.1	F	0454	4.8
	1755	5.0		1659	5.7		1857	3.3		1818	2.8		1131	8.5		1135	9.5
	2149	5.8		2036	6.2								1843	2.1		1840	0.8
14	0433	1.4	29	0339	0.6	14	0032	5.3	29	0025	6.1	14	0145	5.8	29	0207	7.3
SU	1242	8.0	M	1149	8.5	W	0537	3.1	TH	0518	3.3	F	0537	4.9	SA	0605	5.7
	1847	4.5		1754	4.9		1245	8.2		1222	9.3		1202	8.5		1217	9.4
	2319	5.6		2227	6.1		1925	2.5		1900	1.5		1915	1.2		1923	-0.1
15	0534	1.8	30	0448	1.1	15	0146	5.8	30	0152	6.9	15	0248	6.6	30	0313	8.2
M	1325	8.0	TU	1235	8.6	TH	0633	3.7	F	0627	4.2	SA	0636	5.5	SU	0715	6.4
	1925	3.9		1836	3.9		1312	8.1		1300	9.2		1231	8.4		1258	9.1
							1954	1.7		1942	0.4		1942	0.4		2005	-0.8
			31	0008	6.3										31	0405	8.8
			W	0554	1.7										M	0818	6.7
				1315	8.7											1339	8.9
				1917	2.7											2043	-1.2

TIME MERIDIAN 120° W. 0000 IS MIDNIGHT. 1200 IS NOON.
HEIGHTS ARE REFERRED TO MEAN LOWER LOW WATER WHICH IS THE CHART DATUM OF SOUNDINGS.

Step 4. Set up a table like this, and solve.

	High	Low	High	Low
Port Townsend	0025	0518	1222	1900
Correction	+014	+046	+014	+046
Mystery Bay	0039	0604	1236	1946

Step 5. Report tide times for November 29, 1979, as follows:

High tide at	0039 hrs.
Low tide at	0604 hrs.
High tide at	1236 hrs.
Low tide at	1946 hrs.

Exercise B - High and Low Tides for Shelton

Find the times and heights of the high and low tides for Shelton, Oakland Bay, Washington, for December 20, 1979.

Step 1. Page 177 is duplicated for your use. The "Height" column under "Differences" on page 177 states that the height of high water for Shelton, Oakland Bay, is 2.8 feet higher than the reference station, Seattle, Washington. The height of the low water for Shelton is 0.2 feet less than the reference station, Seattle, Washington.

Step 2. Compute as follows:

	High		Low	
Seattle	0615 hrs.	12.5 ft.	1137 hrs.	6.9 ft.
Correction	+112	2.8	+154	-0.2
Shelton	0727	15.3	1331 hrs.	6.7 ft.
	High		Low	
Seattle	1625	11.0 ft.	2335 hrs.	-2.1 ft.
Correction	+112	2.8	+154	-0.2
Shelton	1737 hrs.	13.8 ft.	0129 hrs. (next day)	-2.3 ft.

No.	PLACE	POSITION		DIFFERENCES				RANGES		Mean Tide Level
				Time		Height				
		Lat.	Long.	High water	Low water	High water	Low water	Mean	Diurnal	
		° ′	° ′	h. m.	h. m.	feet	feet	feet	feet	feet
	WASHINGTON—Continued									
	Admiralty Inlet—Continued	N.	W.	on PORT TOWNSEND, p.88						
	Time meridian, 120°W.									
897	Port Townsend (Point Hudson)	48 07	122 45	-0 10	-0 08	+0.2	+0.1	5.3	8.6	5.2
899	Marrowstone Point	48 06	122 41	+0 03	+0 03	+0.4	0.0	5.6	8.8	5.3
900	Mystery Bay, Marrowstone Island	48 03	122 41	+0 14	+0 46	-0.2	0.0	5.0	8.2	5.0
901	Bush Point	48 02	122 36	+0 33	+1 09	+0.4	0.0	5.6	8.8	5.3
902	Oak Bay	48 01	122 43	+0 09	+0 25	+0.9	+0.1	6.0	9.4	5.6
	Hood Canal			on SEATTLE, p.92						
903	Port Ludlow	47 55	122 41	-0 27	-0 18	*0.88	*0.88	6.4	9.9	5.9
905	Port Gamble	47 52	122 35	-0 16	-0 08	*0.91	*0.91	6.7	10.3	6.1
907	Bangor Wharf	47 45	122 44	-0 20	+0 04	-0.3	0.0	7.3	10.9	6.4
908	Zelatched Point, Dabob Bay	47 43	122 49	-0 09	-0 05	+0.1	+0.1	7.6	11.5	6.7
909	Seabuck	47 38	122 50	-0 03	+0 03	+0.3	+0.1	7.8	11.6	6.8
910	Pleasant Harbor	47 40	122 55	-0 14	+0 01	+0.2	+0.1	7.7	11.6	6.8
911	Union	47 21	123 06	-0 04	+0 10	+0.4	+0.1	7.9	11.8	6.9
	Puget Sound									
912	Hansville	47 55	122 33	-0 07	+0 04	-1.0	-0.1	6.7	10.3	6.1
913	Point No Point	47 55	122 32	-0 16	-0 16	*0.92	*0.92	6.7	10.4	6.1
914	Edmonds	47 49	122 23	-0 05	+0 02	-0.4	0.0	7.2	10.9	6.4
915	Port Madison	47 42	122 32	-0 08	-0 08	+0.1	0.0	7.7	11.4	6.6
917	Poulsbo, Liberty Bay	47 44	122 39	+0 02	+0 08	+0.6	+0.1	8.1	11.9	6.9
919	Brownsville, Port Orchard	47 39	122 37	+0 02	+0 08	+0.4	0.0	8.0	11.7	6.8
921	SEATTLE (Madison St.), Elliott Bay	47 36	122 20	Daily predictions				7.6	11.3	6.6
923	Eighth Ave. S., Duwamish Waterway	47 32	122 19	+0 05	+0 07	-0.1	0.0	7.5	11.1	6.5
925	Port Blakely	47 36	122 30	+0 02	+0 03	+0.2	0.0	7.8	11.5	6.7
927	Pleasant Beach, Rich Passage	47 36	122 32	+0 01	+0 07	+0.2	0.0	7.8	11.5	6.7
929	Bremerton, Port Orchard	47 33	122 38	+0 07	+0 12	+0.4	0.0	8.0	11.7	6.8
931	Tracyton, Dyes Inlet	47 37	122 40	+0 30	+0 56	+1.0	0.0	8.6	12.3	7.1
933	South Colby, Yukon Harbor	47 31	122 32	+0 01	+0 07	+0.3	0.0	7.9	11.6	6.7
935	Des Moines	47 24	122 20	+0 03	+0 09	+0.4	0.0	8.0	11.7	6.8
937	Burton, Quartermaster Harbor	47 23	122 28	+0 07	+0 13	+0.6	0.0	8.2	11.9	6.9
939	Gig Harbor	47 20	122 35	+0 06	+0 14	+0.6	0.0	8.2	11.8	6.9
941	Tacoma, Commencement Bay	47 17	122 25	+0 07	+0 06	+0.5	0.0	8.1	11.8	6.8
943	Arletta, Hale Passage	47 17	122 39	+0 23	+0 36	+1.7	0.0	9.3	13.0	7.4
945	Home, Von Geldern Cove, Carr Inlet	47 16	122 45	+0 27	+0 39	+2.3	+0.2	9.7	13.6	7.8
947	Wauna, Carr Inlet	47 23	122 38	+0 20	+0 36	+1.8	0.0	9.4	13.1	7.5
949	Steilacoom	47 10	122 36	+0 22	+0 35	+1.8	0.0	9.4	13.1	7.5
951	Hyde Point, McNeil Island	47 12	122 39	+0 23	+0 41	+2.1	+0.2	9.5	13.4	7.7
953	Sequalitchew Creek, Nisqually Reach	47 07	122 40	+0 24	+0 42	+2.1	+0.1	9.6	13.4	7.7
955	Longbranch, Filucy Bay	47 13	122 45	+0 26	+0 39	+2.2	+0.1	9.7	13.5	7.7
957	Henderson Inlet	47 09	122 50	+0 27	+0 45	+2.6	+0.2	10.0	14.0	8.0
959	Vaughn, Case Inlet	47 20	122 46	+0 35	+0 47	+2.8	+0.2	10.2	14.1	8.1
961	Allyn, Case Inlet	47 23	122 49	+0 27	+0 46	+2.8	+0.2	10.2	14.1	8.1
963	Walkers Landing, Pickering Passage	47 17	122 56	+0 35	+0 47	+2.9	+0.2	10.3	14.3	8.1
965	Arcadia, Pickering Passage	47 12	122 56	+0 35	+0 54	+3.0	+0.2	10.4	14.4	8.2
967	Shelton, Oakland Bay	47 13	123 05	+1 12	+1 54	+2.8	-0.2	10.6	14.2	7.9
969	Burns Point, Totten Inlet	47 07	123 03	+0 36	+0 54	+3.6	+0.2	11.0	15.0	8.5
971	Rocky Point, Eld Inlet	47 04	123 01	+0 34	+0 52	+3.3	+0.3	10.6	14.7	8.4
973	Dofflemyer Point, Budd Inlet	47 08	122 54	+0 29	+0 47	+3.1	+0.2	10.5	14.4	8.2
975	Olympia, Budd Inlet	47 03	122 54	+0 31	+0 46	+3.1	+0.2	10.5	14.4	8.2
	Possession Sound and Port Susan									
977	Mukilteo	47 57	122 18	-0 08	-0 12	-0.3	-0.1	7.4	11.0	6.4
979	Everett	47 59	122 13	-0 09	-0 11	-0.2	0.0	7.4	11.1	6.5
981	Tulalip	48 04	122 17	+0 02	-0 02	0.0	0.0	7.6	11.2	6.6
982	Kayak Point	48 08	122 22	-0 04	-0 01	-0.4	-0.1	7.3	10.9	6.3
983	Stanwood,[1] Stillaguamish River	48 14	122 22	+0 18	+2 10	*0.63	*0.29	5.7	7.4	3.6

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*Ratio.

[1] The low water seldom falls below the chart datum.

TIMES AND HEIGHTS OF HIGH AND LOW WATERS

OCTOBER

DAY	TIME h.m.	HT. ft.	DAY	TIME h.m.	HT. ft.
1	0620	0.6	16	0126	8.4
M	1334	11.0	TU	0735	2.5
	1926	5.3		1429	10.8
				2042	3.9
2	0039	9.[illegible]	17	0222	8.8
TU	0724	0.6	W	0821	2.7
	1420	11.4		1457	10.8
	2020	4.2		2113	3.2
3	0148	9.8	18	0311	9.3
W	0820	0.6	TH	0902	3.0
	1500	11.7		1523	10.8
	2107	3.0		2142	2.4
4	0254	10.5	19	0355	9.8
TH	0912	0.9	F	0941	3.4
	1537	11.9		1544	10.7
	2149	1.7		2211	1.[illegible]
5	0353	11.0	20	0433	10.2
F	1001	1.4	SA	1016	3.7
	1614	12.0		1608	10.7
	2234	0.6		2239	0.9
6	0450	11.4	21	0512	10.6
SA	1048	2.1	SU	1051	4.2
	1649	11.9		1630	10.7
	2316	-0.2		2311	0.3
7	0546	11.6	22	0550	10.9
SU	1135	3.0	M	1130	4.6
	1727	11.7		1658	10.6
				2343	-0.1
8	0002	-0.7	23	0633	11.1
M	0641	11.6	TU	1209	5.1
	1224	3.9		1727	10.5
	1806	11.3			
9	004[illegible]	-0.8	24	0020	-0.4
TU	074[illegible]	11.4	W	0715	11.2
	1313	4.8		1251	5.6
	1846	10.7		1758	10.3
10	0135	-0.5	25	0100	-0.5
W	0843	11.1	TH	0807	11.2
	1408	5.5		1341	6.1
	1931	10.0		1841	10.0
11	0225	0.1	26	0145	-0.4
TH	0948	10.8	F	0901	11.2
	1516	6.1		1437	6.4
	2022	9.2		1926	9.5
12	0323	0.7	27	0236	0.0
F	1057	10.6	SA	1000	11.2
	1635	6.3		1543	6.5
	2124	8.5		2028	9.0
13	0425	1.4	28	0333	0.4
SA	1207	10.6	SU	1100	11.3
	1805	6.0		1702	6.1
	2247	8.1		2148	8.6
14	0533	1.9	29	0437	1.0
SU	1302	10.7	M	1157	11.5
	1916	5.4		1815	5.2
				2317	8.5
15	0013	8.1	30	0546	1.6
M	0639	2.2	TU	1247	11.7
	1350	10.8		1914	4.0
	2003	4.7			
			31	0042	8.9
			W	0652	2.1
				1335	11.9
				2003	2.6

NOVEMBER

DAY	TIME h.m.	HT. ft.	DAY	TIME h.m.	HT. ft.
1	0200	9.6	16	0306	9.3
TH	0754	2.6	F	0823	4.8
	1414	12.0		1421	10.9
	2051	1.2		2107	1.3
2	0307	10.4	17	0353	10.0
F	0850	3.2	SA	0908	5.2
	1454	12.1		1447	10.9
	2132	0.0		2140	0.5
3	0406	11.2	18	0431	10.6
SA	0942	3.8	SU	0950	5.6
	1531	12.0		1513	10.9
	2214	-1.0		2209	-0.2
4	0502	11.7	19	0510	11.1
SU	1031	4.4	M	1029	5.9
	1609	11.8		1544	10.9
	2257	-1.5		2242	-0.9
5	0554	12.1	20	0549	11.6
M	1121	5.0	TU	1111	6.2
	1645	11.4		1612	10.9
	2336	-1.7		2317	-1.3
6	0643	12.2	21	0627	11.9
TU	1209	5.5	W	1153	6.4
	1723	10.9		1647	10.8
				2353	-1.5
7	0018	-1.5	22	0709	12.2
W	0735	12.1	TH	1239	6.6
	1300	6.0		1727	10.5
	1804	10.3			
8	0103	-1.0	23	0035	-1.5
TH	0827	11.9	F	0755	12.3
	1358	6.3		1331	6.6
	1847	9.6		1809	10.1
9	0148	-0.2	24	0121	-1.1
F	0919	11.7	SA	0843	12.4
	1503	6.5		1428	6.5
	1936	8.8		1907	9.5
10	0237	0.7	25	0210	-0.4
SA	1015	11.5	SU	0933	12.4
	1617	6.3		1533	6.1
	2045	8.1		2016	8.8
11	0332	1.6	26	0306	0.6
SU	1112	11.3	M	1025	12.3
	1736	5.8		1644	5.3
	2205	7.6		2142	8.3
12	0430	2.5	27	0405	1.7
M	1202	11.2	TU	1115	12.3
	1842	5.0		1753	4.1
	2341	7.5		2316	8.2
13	0536	3.2	28	0511	2.8
TU	1247	11.1	W	1204	12.3
	1927	4.1		1852	2.7
14	0109	7.9	29	0052	8.7
W	0639	3.9	TH	0623	3.8
	1322	11.0		1250	12.3
	2005	3.2		1946	1.3
15	0212	8.6	30	0214	9.6
TH	0737	4.4	F	0729	4.7
	1353	10.9		1332	12.2
	2038	2.2		2033	0.0

DECEMBER

DAY	TIME h.m.	HT. ft.	DAY	TIME h.m.	HT. ft.
1	0319	10.5	16	0344	10.1
SA	0832	5.3	SU	0834	6.7
	1414	12.1		1354	11.0
	2115	-1.0		2106	-0.1
2	0418	11.4	17	0425	10.8
SU	0928	5.8	M	0923	6.9
	1455	11.9		1427	11.0
	2157	-1.7		2142	-0.9
3	0507	12.0	18	0501	11.5
M	1022	6.1	TU	1009	7.0
	1534	11.6		1505	11.1
	2239	-2.0		2219	-1.5
4	0555	12.4	19	0539	12.1
TU	1111	6.4	W	1052	7.0
	1612	11.2		1543	11.1
	2317	-1.9		2256	-2.0
5	0637	12.6	20	0615	12.5
W	1158	6.6	TH	1137	6.9
	1654	10.7		1625	11.0
	2356	-1.6		2335	-2.1
6	0723	12.6	21	0654	12.8
TH	1248	6.6	F	1225	6.7
	1733	10.1		1711	10.8
7	0035	-1.0	22	0017	-1.9
F	0805	12.4	SA	0733	13.0
	1340	6.6		1316	6.3
	1819	9.5		1803	10.3
8	0118	-0.3	23	0102	-1.2
SA	0848	12.3	SU	0816	13.1
	1435	6.4		1410	5.8
	1911	8.8		1905	9.7
9	0200	0.7	24	0151	-0.2
SU	0930	12.0	M	0900	13.0
	1538	6.1		1512	5.0
	2010	8.1		2018	9.0
10	0245	1.7	25	0240	1.1
M	1013	11.8	TU	0945	12.9
	1640	5.5		1618	4.1
	2125	7.6		2141	8.5
11	0338	2.9	26	0337	2.6
TU	1054	11.6	W	1033	12.7
	1743	4.7		1726	2.9
	2257	7.4		2319	8.4
12	0433	3.9	27	0441	4.1
W	1135	11.4	TH	1121	12.5
	1835	3.8		1826	1.7
13	0031	7.7	28	0058	8.9
TH	0536	4.9	F	0557	5.4
	1211	11.2		1208	12.2
	1920	2.7		1922	0.5
14	0149	8.4	29	0225	9.8
F	0641	5.7	SA	0711	6.2
	1247	11.1		1255	12.0
	1959	1.7		2014	-0.5
15	0252	9.2	30	0327	10.8
SA	0741	6.3	SU	0821	6.7
	1319	11.0		1344	11.7
	2034	0.8		2101	-1.2
			31	0423	11.6
			M	0923	6.9
				1429	11.5
				2142	-1.6

TIME MERIDIAN 120° W. 0000 IS MIDNIGHT. 1200 IS NOON.
HEIGHTS ARE REFERRED TO MEAN LOWER LOW WATER WHICH IS THE CHART DATUM OF SOUNDINGS.

Step 3. Report the times and heights for December 20, 1979, as follows:

High Tide at 0727 hrs. Height: 15.3 ft.
Low Tide at 1331 hrs. Height: 6.7 ft.
High Tide at 1737 hrs. Height: 13.8 ft.
Low Tide at 0129 hrs. Height: -2.3 ft.

Exercise C - Tidal Range at Shelton

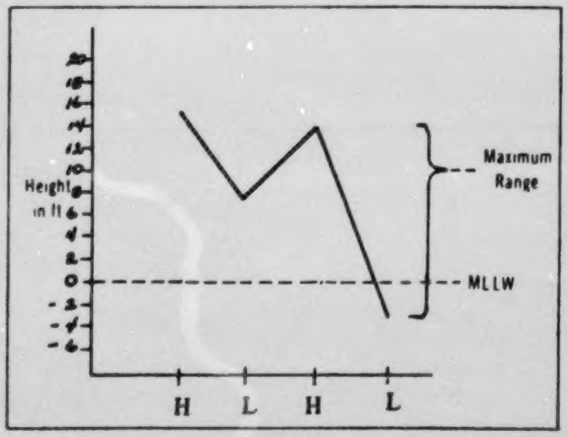
What is the maximum tidal range for December 20, 1979, at Shelton, Oakland Bay, Washington?

Step 1. From exercise B the heights for high and low waters were found to be:

High = 15.3 ft.
Low = 6.7 ft.
High = 13.8 ft.
Low = -2.3 ft.

All heights in the Tide Table are figured at Mean Lower Low Water (M.L.L.W.). Tidal range is the difference in height of succeeding high and low tides.

Step 2. Graphically represent the data:



Note: (1) That the second low of the day is predicted to be 2.3 feet below Mean Lower Low Water; and (2) that the second high of the day is predicted to be 13.8 feet above Mean Lower Low Water.

Step 3. The maximum range for this date and location is predicted as: 16.1 feet (i.e., 13.8 ft. - (-2.3 ft.) = 16.1 ft.).

Step 4. The range between the first high and the first low on this day is called the minimum range. The minimum range for this date and this place is predicted as: 8.6 feet (i.e., 15.3 ft. - 6.7 ft. = 8.6 ft.).

Exercise D - High and Low Tides for Olympia

Step 1. Pages 95 and 177 are duplicated for your use. Find the times and heights for the high and low tides for Olympia, Budd Inlet, Washington, for December 15, 1979.

	High		Low		High		Low	
	Time	Height	Time	Height	Time	Height	Time	Height
Seattle								
Correction								
Olympia								

Step 2. Find the maximum tidal range for October 31, 1979, for Port Madison, Washington. Show the tidal ranges graphically.

Analysis and Interpretation:

1. Explain why tides are different at different times and places.

2. Are there any local hazards due to tides?

3. The Tide Tables state "Heights are reckoned from the datum of soundings on charts of the locality which is Mean Lower Low Water." What significance does this have to the pilot of an ocean-going vessel?

4. Why are vertical clearances of bridges along navigable water given as heights in feet above mean high water?

5. Why do the tides differ in time between Mystery Bay, Washington, and Port Townsend, Washington?

6. Would knowledge of tides be of any importance in a military landing action?

7. Why do tidal "bulges" occur on both sides of the earth at the same time?

8. How do intertidal organisms cope with such a dynamic, ever-changing environment?

9. What are the relative positions of the earth, moon and sun during (a) spring tides and (b) neap tides?

TEACHER BACKGROUND - Types of Tides

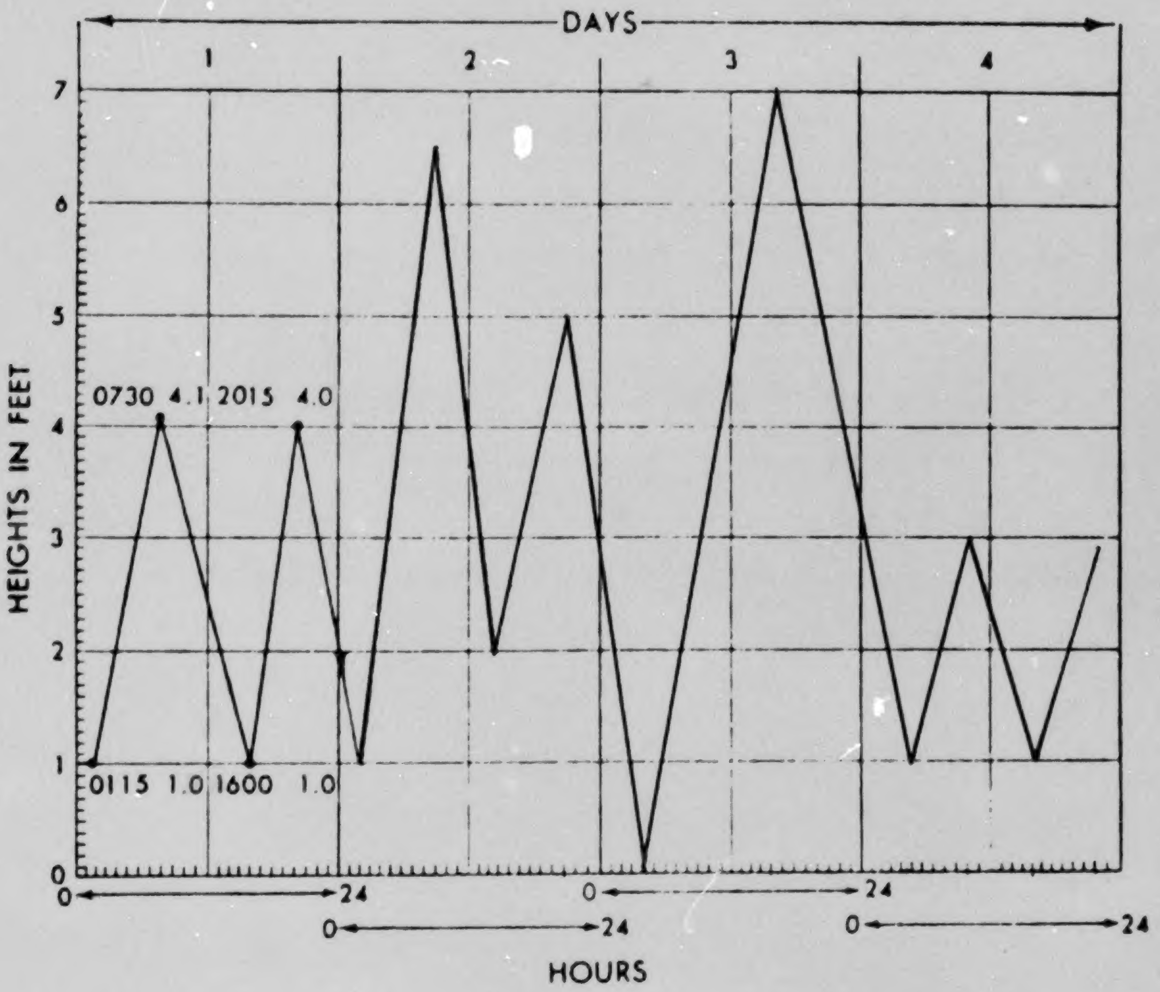
Real tides change with geographic location. Tides are generally classified as one of three types: semidiurnal, diurnal or mixed. "Types of Tides" introduces your students to these three types of tides and to their similarities and differences. "Understanding Tides," the Oregon State University Extension Marine Advisory Program publication, provides additional background information on the types of tides.

Duplicate the activity pages. One set is recommended per student. The figures in the text can be used as samples from which your students can prepare a marigram from the given tide predictions. In addition, the first day's data is plotted on the graph provided. This activity may be performed individually or in small groups. Plan to spend some time in a discussion of the results.

KEY

1. The tide is diurnal on day three. There is one high water and one low water.
2. The tide is mixed on day two. There are two high waters and two low waters each day but with considerable difference between heights of successive high waters or successive low waters.
3. The tide is semidiurnal on day one and day four. There are two high waters and two low waters each day with little or no difference between consecutive high or low water heights.
4. The range is the largest on day three.
5. The smallest range is 1.9 feet on day four.
6. The largest diurnal inequality shown is 1.5 feet on day two.
7. No, one would not expect to find a location in real life where the types of tides changed daily. The data is used as an example to show the different types of tides and does not represent tides at a particular location.

Tide Predictions Marigram



KEY WORDS

diurnal inequalities

diurnal tide

graphic

kinetic

marigram

mixed tide

semidiurnal tide

theoretical

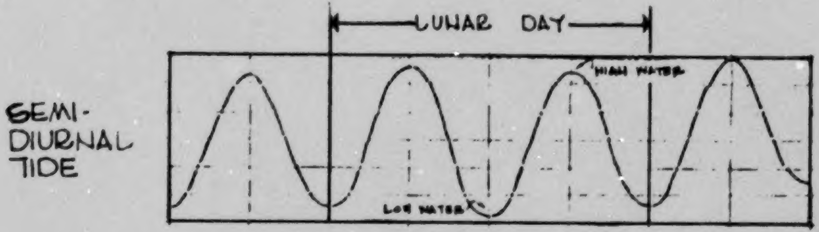
TYPES OF TIDES

If the tides agreed with the theory we would see two equal high and two equal low tides each lunar day (24 hours and 50 minutes.) The real tides, however, vary from the theoretical tides due to the irregularity of the oceans and land masses. In the real world, it is important to know the times and heights of the real tides. Information about the tides has always been of great importance to navigation, especially in guiding ships in and out of shallow waters near shore and around islands. Tidal information is necessary to design electrical generating plants to capture the kinetic energy (energy due to movement) of the tides.

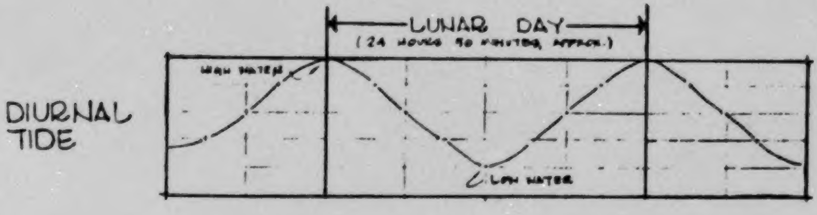
One of man's early goals was to predict the tides. By taking observations of the time and amount of rise and fall each day over a long period of time, basic characteristics of the local tide are discovered and predictions can be made regarding future tides. A marigram is a graphic record of the rise and fall of the tide at a given location.

The recording of marigrams at many locations has shown us that there are general characteristics of the tides throughout the world that allow us to classify them as three types. The three general types of tides are:

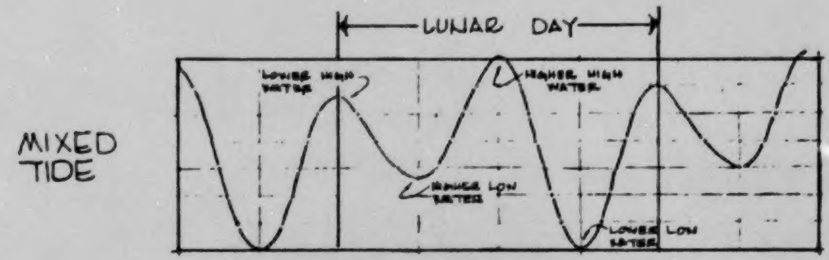
(1) SEMIDIURNAL type, which has two high waters and two low waters each day with little or no difference between consecutive high or low water heights. Tides along the east coast of the United States, for example, are of the semidiurnal type.


LUNAR DAY
SEMI-DIURNAL TIDE
HIGH WATER
LOW WATER

(2) DIURNAL type, which has only one high water and one low water each day. The tides along the Vietnam-China coast are diurnal.


LUNAR DAY
(24 HOURS 50 MINUTES, APPROX.)
DIURNAL TIDE
HIGH WATER
LOW WATER

(3) MIXED type, which has both diurnal and semidiurnal characteristics. That is, there are two high waters and two low waters each day but with considerable difference between heights of successive high waters or successive low waters; these differences are called DIURNAL (daily) INEQUALITIES. The tides along the Pacific coast of the United States are mixed.


LUNAR DAY
MIXED TIDE
LOWER HIGH WATER
HIGHER HIGH WATER
HIGHER LOW WATER
LOWER LOW WATER

Procedure:

1. The table below shows examples of different tide types. Plot a marigram or tide curve from the tide predictions given below. The first day has been plotted on the accompaning graph. Complete the tide curves for days 2, 3, and 4 by plotting the times and heights. Connect all the points.
2. Answer the questions based upon your graph.

TIDE PREDICTIONS

DAYS	TIME*		HEIGHTS*
	Hours	Minutes	Feet
1	01	15	1.0
	07	30	4.1
	16	00	1.0
	20	15	4.0
2	02	00	1.0
	08	30	6.5
	14	15	2.0
	21	00	5.0
3	04	15	0.0
	16	00	7.0
4	04	30	1.0
	10	00	3.0
	16	00	1.0
	22	00	2.9

* The days are divided into 24 hours (0 to 24), midnight to midnight. Heights are measured from the zero reference line.

Questions:

1.) During what day is the tide diurnal?______________________________

2.) During what day is the tide mixed? ______________________________

3.) During what days is the tide semidiurnal? ____________________

4.) During what day is the range largest? (The ranges is the difference (subtract) between the highest and lowest tides.) ______________

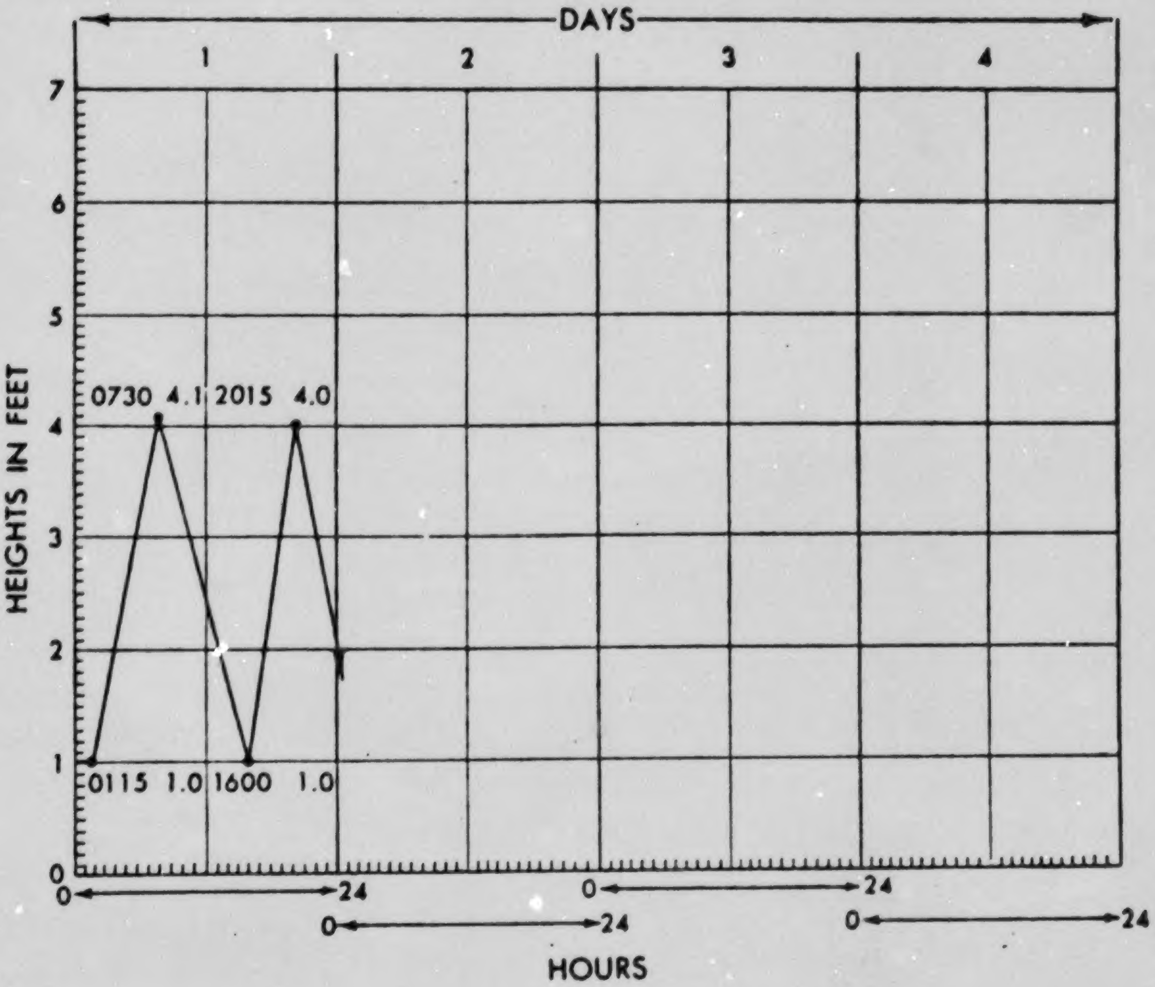
____

5.) What is the smallest range? ______________ft. On what day?
Day ________________.

6.) What is the largest diurnal inequality shown? ______________ft.
On what day? Day ______________.

7.) Would you expect to find a single, real geographic location with tides like those shown in the table? Explain.

Tide Predictions Marigram:



TEACHER BACKGROUND - Tide Tables Too?

"Tide Tables Too?" provides practice with the type of tide tables your students will most often see. This exercise helps to reinforce the concept that the tides are regular and predictable. Additional practice can be provided through the purchase of a fisherman's tide table or by use of the tide tables printed in newspapers distributed along the coasts.

Duplicate the activity pages. One set is recommended per student. Although the format of these tide tables is different from that of those produced by the U.S. government, the information is the same and your students should be able to make the transfer without much trouble. Recommend that your students read the introduction to the table and look over the correction table and bridge clearances and signals. Students may work singly or in small groups. Each approach has its merits. Offer such assistance as may be necessary for successful completion of the activity. The one you choose will depend upon your class and your particular situation. Upon completion, plan to allow a few minutes to discuss the activity and to provide the correct answers.

KEY

1. The lowest tide expected to occur on December 1 is minus 2.5 feet (-2.5 ft.). This tide will occur at Seattle at 2332 hours.
2. The time of the highest high tide of December 25 at Shelton, Oakland Bay is 1:53 p.m. (12:23 p.m. + 1:30 = 1:53 p.m.) or 1353 hours. The height of this tide at Shelton, Oakland Bay will be 14.2 feet (11.4 ft + 2.8 ft = 14.2 ft.).
3. The best tides available which fit into Mr. P. Lanahead's schedule are:

Time	Date	Height
0908 hours	Dec 11	6.1 feet
1004 hours	Dec 12	6.5 feet
1055 hours	Dec 13	6.7 feet
1140 hours	Dec 14	6.8 feet

While there are some good low tides in December, none of them fall within the time restrictions under which Mr. P. Lanahead is working. He might be better off staying at home in December!

4. During December the tides occurring in the Seattle District are mixed with diurnal inequalities.

5. The following is a completed table for December 13 at Port Townsend:

	TIMES			
	High	Low	High	Low
Port Townsend	0437 hours	0900 hours	1410 hours	2128 hours
Correction for Chuckanut Bay	+50 hours	+50 hours	+50 hours	+50 hours
Chuckanut Bay	0527 hours	0950 hours	1500 hours	2218 hours

6. The differences in time between the first high tide at Port Townsend and the first high tide at Seattle for the following dates are:

December 1	17 minutes
December 3	14 minutes
December 10	32 minutes
December 17	11 minutes
December 24	20 minutes
December 31	17 minutes

No, the difference is not the same every day. The average difference in time is 18.5 minutes (111 minutes/6 days = 18.5 minutes/day). The average is more likely to be correct than any one of the individual times. The average tends to minimize the effect of the extreme time differences.

7. a. The heights are given in feet above Mean High Water because navigators can readily use this figure to determine if a vessel of their height can fit under the bridge. Clearance will be minimum on the high tides.

b. The height of the Fox Island Bridge under the center of the span is 31 feet above Mean High Water.

c. Maximum vertical clearance would occur at 2253 hours (10:53 p.m.) on December 14. As far as height is concerned this would be the safest time.

KEY WORDS

correction table
diurnal tide
Mean High Water
mixed tide
semidiurnal tide
tidal difference
tide pool

TIDE TABLES TOO?

Local tide tables are printed to help fishermen and navigators. The format of these tables is different from those issued by the U.S. government. The last three pages of this exercise are copies of pages from a tide table sold to fishermen. Included is an explanation of tidal differences from the given measuring location (either Seattle or Port Townsend Washington). Use this information to answer the following questions.

1. For Seattle, what is the lowest tide expected to occur on December 1?

   USING THE 24 HOUR CLOCK, at what time will this tide occur at Seattle?

2. Using the correction table for the Seattle District, find the time of the highest high tide of December 25 at Shelton, Oakland Bay. Record this figure using the 24 hour clock as well as the conventional clock.

   What will be the height of this tide at Shelton, Oakland Bay?

3. Mr. P. Lanahead is planning a December trip to examine tide pool life at Rocky Point. Use the tide table for the Seattle District and the correction table to pick out the four best dates for Mr. P. Lanahead and his class. Bear in mind that he will want to leave school at about 0800 hours and that it will take him about 1 hour to get to the beach. (He can leave later, but not earlier and he should return by 1530 hours). LOW TIDES ARE BEST FOR TIDE POOLING!!!!!

   RECORD the times of the four tides, the dates, and the heights of the tides. BE SURE TO CORRECT FOR THE CHANGE IN LOCATION.

4. What TYPE of tides are occurring in the Seattle District during December: diurnal, semi-diurnal, or mixed? How did you arrive at your answer?

INTRODUCTION

This book contains schedules of predicted tide changes with better fishing days indicated with DOTS of increasing size. Also contained are many pages of interesting and valuable information for ship captains, fishermen, sportsmen and visitors to the Pacific Coast. BE SURE to refer to CORRECTION TABLE to adjust time and height to your location.

Tide schedules are furnished by the National Ocean Survey, National Oceanic & Atmospheric Administration from calculations established by the known and predictable forces at established reference stations and are corrected periodically from studies of actual observations. The publisher of Dot's Fishing Guide is constantly in touch with this and other government agencies in its efforts to maintain up to date, accurate information.

"HIGH" Tide predictions are on the LEFT hand pages.

"LOW" Tide predictions are on the RIGHT hand pages.

"A.M." Times are mornings from 0:00 (Midnight) to NOON and are printed in light face type.

"P.M." Times are afternoons and evenings from NOON to 0:00 (Midnight) and are printed in **BOLD TYPE**.

"FT" represents the height of the tide water in feet and tenths of a foot above, or — below, a fixed reference point of 0.0 Zero.

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CORRECTION TABLE
SOUTHERN PUGET SOUND
SEATTLE DISTRICT

To correct the TIME of HIGH or LOW tides for the points given below, add or subtract TIME from the SEATTLE District Tide Table. Also, add or subtract FEET to correct the HEIGHT of the HIGH TIDE.

HOOD CANAL	Time	Feet
Port Ludlow	−0:20	*.88
Port Gamble	−0:15	*.91
Seabeck	0:00	+0.3
Union	0:00	+0.4
PUGET SOUND		
Point No Point	−0:15	*.92
Port Madison	−0:10	+0.1
Poulsbo, Liberty Bay	+0:05	+0.6
Brownsville, Port Orchard	+0:05	+0.4
SEATTLE (Mdsn St.) Elliott Bay	0:00	0.0
Eighth Ave. S., Duwamish River	+0:05	−0.1
Port Blakely	0:00	+0.2
Pleasant Beach, Rich Passage	+0:05	+0.2
Bremerton, Port Orchard	+0:10	+0.4
Tracyton, Dyes Inlet	+0:45	+1.0
South Colby, Yukon Harbor	+0:05	+0.3
Des Moines	+0:05	+0.4
Burton, Quartermaster Harbor	+0:10	+0.6
Gig Harbor	+0:10	+0.6
Tacoma, Commencement Bay	+0:05	+0.5
Arletta, Hale Passage	+0:30	+1.7
Home, Von Gldrn Cove, Car Inlt	+0:35	+2.3
Wauna, Carr Inlet	+0:35	+1.8
Steilacoom	+0:30	+1.8
Hyde Point, McNeil Island	+0:30	+2.1
Sequalitchew Crk, Nisq. Reach	+0:30	+2.1
Longbranch, Filucy Bay	+0:30	+2.2
Henderson Inlet	+0:35	+2.6
Vaughn, Case Inlet	+0:40	+2.8
Allyn, Case Inlet	+0:35	+2.8
Walkers Land., Pickering Pass	+0:40	+2.9
Arcadia, Pickering Passage	+0:45	+3.0
Shelton, Oakland Bay	+1:30	+2.8
Burns Point, Totten Inlet	+0:45	+3.6
Rocky Point, Eld Inlet	+0:45	+3.3
Dofflemyer Point, Budd Inlet	+0:35	+3.1
Olympia, Budd Inlet	+0:40	+3.1
POSSESSION SOUND and PORT SUSAN		
Mukilteo	−0:10	−0.3
Everett	−0:10	−0.2
Tulalip	0:00	0.0
Kayak Point	0:00	−0.4
Stanwood, StillaguamishRiver	+0:20h +2:10L	*.63 *.29
SARATOGA PASSAGE and SKAGIT BAY		
Greenbank, Whidbey Island	−0:05	0.0
Coupeville, Penn Cove	0:00	+0.2
La Conner, Swinomish Channel	+0:30	*.88
Ala Spit	+0:20	*.92
Yokeko Point, Deception Pass	+0:30	−0.3
Cornet Bay, Deception Pass	+0:20	*.88

* = multiply height of District Tide by this ratio to correct for high water.

SOUTHERN PUGET SOUND TIDES

HIGH Tides SEATTLE District
DECEMBER 1978

DATE	DAY	DOT'S GUIDE	A. M. TIME	A. M. FT.	P. M. TIME	P. M. FT.
1	Fri	•	6:02	12.5	**4:23**	**11.5**
2	Sat	•	6:47	12.8	**5:11**	**11.2**
3	SUN	•	7:33	12.9	**6:03**	**10.7**
4	Mon	•	8:21	13.0	**7:02**	**9.9**
5	Tues	•	9:13	12.9	**8:15**	**9.1**
6	Wed	•	10:03	12.7	**9:41**	**8.5**
7	Thur	•	10:54	12.5	**11:20**	**8.3**
8	Fri	•	11:42	12.3	...	..
9	Sat	•	0:59	8.7	**12:31**	**12.1**
10	SUN	•	2:21	9.5	**1:15**	**11.8**
11	Mon	●	3:24	10.4	**1:56**	**11.5**
12	Tues	●	4:19	11.1	**2:36**	**11.2**
13	Wed	●	5:05	11.7	**3:11**	**11.0**
14	Thur	●	5:43	12.0	**3:47**	**10.7**
15	Fri	●	6:19	12.2	**4:22**	**10.4**
16	Sat	●	6:54	12.3	**4:59**	**10.0**
17	SUN	●	7:26	12.3	**5:39**	**9.7**
18	Mon	●	8:01	12.3	**6:25**	**9.2**
19	Tues	●	8:37	12.2	**7:17**	**8.6**
20	Wed	●	9:12	12.0	**8:16**	**8.1**
21	Thur	●	9:49	11.9	**9:30**	**7.7**
22	Fri	●	10:26	11.7	**10:57**	**7.6**
23	Sat	●	11:03	11.5	...	..
24	SUN	●	0:26	8.0	11:44 AM	11.4
25	Mon	●	1:46	8.8	**12:23**	**11.4**
26	Tues	●	2:51	9.7	**1:02**	**11.4**
27	Wed	•	3:43	10.7	**1:47**	**11.5**
28	Thur	•	4:27	11.6	**2:30**	**11.7**
29	Fri	•	5:08	12.3	**3:18**	**11.7**
30	Sat	•	5:50	12.9	**4:07**	**11.7**
31	SUN	•	6:32	13.2	**5:02**	**11.4**

●BIGGER THE DOT—BETTER THE FISHING

HAPPY NEW YEAR

SOUTHERN PUGET SOUND TIDES

LOW Tides SEATTLE District
DECEMBER 1978

DATE	DAY	DOT'S GUIDE	A. M. TIME	A. M. FT.	P. M. TIME	P. M. FT.
1	Fri	•	11:24	6.5	**11:32**	**−2.5**
2	Sat	•	...	..	**12:14**	**6.5**
3	SUN	•	0:17	−2.4	**1:07**	**6.4**
4	Mon	•	1:04	−1.7	**2:07**	**6.1**
5	Tues	•	1:55	−0.7	**3:15**	**5.5**
6	Wed	•	2:50	0.6	**4:28**	**4.7**
7	Thur	•	3:49	2.1	**5:41**	**3.5**
8	Fri	•	4:55	3.5	**6:43**	**2.3**
9	Sat	•	6:08	4.7	**7:37**	**1.1**
10	SUN	•	7:19	5.5	**8:23**	**0.2**
11	Mon	●	8:23	6.1	**9:06**	**−0.5**
12	Tues	●	9:19	6.5	**9:44**	**−1.0**
13	Wed	●	10:10	6.7	**10:19**	**−1.2**
14	Thur	●	10:55	6.8	**10:53**	**−1.2**
15	Fri	●	11:37	6.8	**11:27**	**−1.1**
16	Sat	●	...	..	**12:15**	**6.8**
17	SUN	●	0:01	−0.8	**1:01**	**6.6**
18	Mon	●	0:36	−0.3	**1:43**	**6.4**
19	Tues	●	1:15	0.4	**2:35**	**6.0**
20	Wed	●	1:56	1.2	**3:27**	**5.5**
21	Thur	●	2:39	2.3	**4:26**	**4.9**
22	Fri	●	3:27	3.4	**5:19**	**4.0**
23	Sat	●	4:23	4.5	**6:11**	**3.0**
24	SUN	●	5:25	5.5	**7:00**	**1.9**
25	Mon	●	6:31	6.3	**7:44**	**0.8**
26	Tues	●	7:33	6.9	**8:23**	**−0.4**
27	Wed	•	8:36	7.1	**9:05**	**−1.4**
28	Thur	•	9:29	7.2	**9:48**	**−2.2**
29	Fri	•	10:19	7.0	**10:31**	**−2.6**
30	Sat	•	11:10	6.7	**11:16**	**−2.7**
31	SUN	•	...	..	**Noon**	**6.3**

STANDARD TIME

ASK FOR DOT'S TIDE BOOKS

5. Complete the following table for December 13 at Port Townsend. USE THE 24 clock.

TIMES

	High	Low	High	Low
Port Townsend				
Correction for Chuckanut Bay				
Chuckanut Bay				

6. What is the difference in time between the first high tide at Port Townsend and the first high tide at Seattle for the following dates:

December 1
December 3
December 10
December 17
December 24
December 31

Is the difference in time the same every day?

What is the average difference in time? (Hint: Add all of the time differences and divide the sum by the number of days to find the average).

If you were going to make a tide table and wanted a correction for the differences between Seattle and Port Townsend, why would you want to use the average rather than any individual date from above?

7. As a pilot on the James A. your destination is Purdy. Use the page marked "Bridge Clearances and Signals" to answer the following questions.

   a. Why are the heights given in feet above Mean High Water?

   b. What is the height of the Fox Island bridge under the center of the span?

   c. On December 14, what would be the safest time for you to pilot your 30 foot tall James A. under the Fox Island bridge?

CORRECTION TABLE

NORTHERN PUGET SOUND
PORT TOWNSEND DISTRICT

To correct the TIME of HIGH or LOW tides for the points given below, add or subtract TIME from the PORT TOWNSEND Tide Table. Also, add or subtract FEET to correct the HEIGHT of the HIGH TIDE.

	Time	Feet
STRAIT OF JUAN DE FUCA		
Cape Flattery, Tatoosh Island	−3:45	−0.4
Neah Bay	−3:35	−0.5
Clallam Bay, Sekiu	−3:05	−0.8
Port Angeles	−1:25	−1.1
Dungeness	−0:40	−0.7
Sequim Bay Entrance	−0:20	−0.4
Gardiner, Port Discovery	−0:30	−0.4
Smith Island	−0:15	−1.0
Point Partridge	−0:10	−0.6
ADMIRALTY INLET		
Admiralty Head	+0:10	+0.1
Port Townsend (Pt. Hudson)	−0:05	+0.3
Marrowstone Point	+0:10	+0.5
Oak Bay	+0:20	+1.0
ROSARIO STRAIT, ETC.		
Reservation Bay, Fidalgo Island	−0:05	−0.6
Aleck Bay, Lopez Island	−0:10	−0.9
Burrows Bay (Allan Island)	+0:10	−0.3
Anacortes, Guemes Channel	+0:30	−0.2
Swinomish Chan. ent., Pad. Bay	+1:00	+0.1
Thatcher Pass	+0:30	−0.2
Strawberry Bay, Cypress Island	+0:45	−0.4
Peavine Pass	+0:30	−0.2
Eagle Harbor, Cypress Island	+0:45	−0.2
BELLINGHAM BAY		
Chuckanut Bay	+0:50	+0.1
Bellingham	+1:00	+0.2
HALE PASSAGE		
Point Migley	+1:00	+0.2
Rosario, East Snd., Orcas Island	+0:50	−0.2
Upright Head, Lopez Island	+0:40	−0.5
Orcas, Orcas Island	+0:50	−0.6
SAN JUAN CHANNEL		
Richardson, Lopez Island	−0:10	−1.0
Friday Harbor, San Juan Island	+0:50	−0.6
STRAIGHT OF GEORGIA		
Echo Bay, Sucia Islands	+1.20	+0.2
Cherry Point (Ferndale)	+1.30	+0.6
Blaine, Semiahmoo Bay	+1.15	+1.0
HARO STRAIT		
Kanaka Bay, San Juan Island	0:00	−1.0
Roche Harbor, San Juan Island	+0:45	−0.7
Turn Point, Stuart Island	+0:40	−0.7
Alden Point, Patos Island	+1:00	+0.7
BRITISH COLUMBIA		
Heights Based on Canadian Chart Datum		
Active Pass, Mayne Island	+1:25	+4.5
Cowichan Bay	+0:45	+2.8
Chemainus, Stuart Channel	+0:50	+3.4
Ladysmith	+0:50	+3.5
Sand Heads, Fraser River	+1:20	+4.4
Atkinson Point, Burrard Inlet	+1:20	+4.4
Vancouver, Burrard Inlet	+1:50	+5.7
Nanaimo	+1:30	+5.7

NORTHERN PUGET SOUND TIDES

HIGH Tides PT. TOWNSEND Dist.
DECEMBER 1978

DATE DAY		DOT'S GUIDE	A. M. TIME	A. M. FT.	P. M. TIME	P. M. FT.
1	Fri	•	5:45	9.1	3:24	8.5
2	Sat	•	6:33	9.3	4:06	8.2
3	SUN	•	7:19	9.4	4:58	7.8
4	Mon	•	8:07	9.4	5:57	7.2
5	Tues	•	8:53	9.4	7:17	6.4
6	Wed	•	9:35	9.3	8:50	5.9
7	Thur	•	10:19	9.2	10:36	5.7
8	Fri	•	11:01	9.1	...	..
9	Sat	•	0:21	6.0	11:42 AM	9.0
10	SUN	•	1:49	6.7	12:21	8.9
11	Mon	●	2:55	7.4	1:00	8.7
12	Tues	●	3:49	8.0	1:35	8.5
13	Wed	●	4:37	8.5	2:10	8.2
14	Thur	●	5:19	8.8	2:43	7.9
15	Fri	●	6:02	9.0	3:17	7.6
16	Sat	●	6:37	9.0	3:50	7.3
17	SUN	●	7:15	9.0	4:21	7.0
18	Mon	●	7:47	9.0	4:54	6.5
19	Tues	●	8:23	8.9	5:45	6.0
20	Wed	●	8:55	8.8	7:05	5.5
21	Thur	●	9:25	8.7	8:40	5.1
22	Fri	●	9:57	8.7	10:19	5.1
23	Sat	●	10:28	8.6	...	..
24	SUN	●	0:06	5.5	11:03 AM	8.6
25	Mon	●	1:32	6.2	11:38 AM	8.6
26	Tues	●	2:31	7.0	12:14	8.7
27	Wed	•	3:23	7.8	12:52	8.8
28	Thur	•	4:10	8.5	1:35	8.8
29	Fri	•	4:54	9.0	2:20	8.8
30	Sat	•	5:33	9.4	3:10	8.7
31	SUN	•	6:15	9.6	4:04	8.3

● BIGGER THE DOT—BETTER THE FISHING

HAPPY NEW YEAR

NORTHERN PUGET SOUND TIDES

LOW Tides PT. TOWNSEND Dist.
DECEMBER 1978

DATE DAY		DOT'S GUIDE	A. M. TIME	A. M. FT.	P. M. TIME	P. M. FT.
1	Fri	•	10:21	6.3	10:43	−2.0
2	Sat	•	11:15	6.4	11:26	−1.9
3	SUN	•	...	..	12:13	6.3
4	Mon	•	0:12	−1.4	1:15	5.9
5	Tues	•	1:01	−0.6	2:28	5.4
6	Wed	•	1:51	0.5	3:53	4.6
7	Thur	•	2:45	1.7	5:23	3.4
8	Fri	•	3:40	2.9	6:16	2.3
9	Sat	•	4:43	4.1	7:05	1.2
10	SUN	•	5:48	5.0	7:45	0.4
11	Mon	●	6:54	5.7	8:21	−0.2
12	Tues	●	8:00	6.2	8:56	−0.6
13	Wed	●	9:00	6.5	9:28	−0.8
14	Thur	●	9:51	6.7	10:00	−0.9
15	Fri	●	10:39	6.7	10:32	−0.8
16	Sat	●	11:21	6.7	11:06	−0.5
17	SUN	●	12:06 PM	6.6	11:41	−0.2
18	Mon	●	...	..	12:55	6.3
19	Tues	●	0:17	0.3	1:51	5.9
20	Wed	●	0:55	1.0	2:57	5.3
21	Thur	●	1:35	1.7	3:56	4.6
22	Fri	●	2:17	2.6	4:48	3.7
23	Sat	●	3:08	3.5	5:30	2.8
24	SUN	●	4:00	4.4	6:09	1.7
25	Mon	●	5:03	5.2	6:51	0.7
26	Tues	●	6:08	5.8	7:33	−0.3
27	Wed	•	7:14	6.3	8:15	−1.2
28	Thur	•	8:13	6.6	8:57	−1.8
29	Fri	•	9:10	6.6	9:42	−2.2
30	Sat	•	10:07	6.5	10:25	−2.1
31	SUN	•	11:02	6.2	11:11	−1.8

STANDARD TIME

ASK FOR DOT'S TIDE BOOKS

BRIDGE CLEARANCES AND SIGNALS

Heights are in feet above Mean High Water.
Long blast —— 4 seconds; Short blast — 1 second.

SEATTLE, Canal and Lake Washington

•Gt. Northern Ry. 43' —— —
Canal Locks —— —— — —
Canal Locks with tow —— —— — — —
Ballard 29' (46' under center of span) —— —
Fremont Ave. 30'
(31' under central 38' span) —— —
University 29'
(46' under center of span) —— — — —
Montlake 30' (46' under central 63' span) —— —

Note: Ballard, Fremont, University and Montlake closed 7:00 to 9:00 AM and 4:00 to 6:00 PM to vessels under 1000 tons except on Saturdays, Sundays and National Holidays.

Evergreen Floating Bridge
(Foster Is. to Evergreen Pt.) —— — —
Fixed East Span 57' Fixed West Span 44'

Note: Closed 7:00 to 9:00 AM and 4:00 to 6:00 PM on weekdays to vessels less than 2000 tons.

Mercer Island Floating Bridge —— —
East and West fixed spans 31' min., 36' max.

Note: Closed 7:00 to 9:00 AM and 4:00 to 6:00 PM to vessels less than 2000 tons.

Mercer Island (East side of Island) 38' ... Permanent

SEATTLE, Duwamish and West Waterway

•2 Spokane St. Highway Bridges 24' (43' at center) and Burlington R.R. Bridge 4'6".
Signal opens all three bridges —— — — —

Note: Closed 6:30 AM to 8:30 AM and 3:45 PM to 5:45 PM to vessels under 5000 tons.

Burlington R.R. only —— —
1st Ave. So. 26' (41' at center) —— —— ——

Note: Closed 6:30 AM to 8:30 AM and 3:45 PM to 5:45 PM to vessels under 40 tons.

14th Ave. So. 21' (36' at center) —— — ——

Note: No closed periods.

LA CONNER, Swinomish Channel

Burlington Northern RR 7.7'; Freeway 73.7'.
•Drawbridge 16.3' down; 78.3' up —— —
Rainbow South Bridge 75.9'; Power cables 72'.

HOOD CANAL

•Draw section of Bridge —— — —
Fixed East Span 55' Fixed West Span 35'

TACOMA, City Waterway

So. 11th St. Highway Bridge —— —
64' Down 139' Up

Note: City bridges closed 6:30-8:30 AM and 3:30-5:30 PM to vessels less than 1000 gross tons.

Union Pacific near So. 15th St. 6' —— — ——

Note Closed 7:15 to 8:00 AM and 4:15 to 5:00 PM.

TACOMA, Puyallup Waterway

E. 11th St. 26' down 138' up not required to open.
E. 11th RR. 12' down.
Open on 24-hour notice —— —— —— — —

TACOMA, PORT INDUSTRIAL (Blair) Waterway

•E. 11th St. 8' at center —— ——

TACOMA, Hylebos Waterway

•E. 11th St. 21' at center —— —

HALE PASSAGE

Fox Island Bridge 31' at center ... Permanent

CARR INLET, Henderson Bay

Raft Island Bridge 17' ... Permanent
Purdy Bridge 12' (22' at center) ... Permanent

CASE INLET

Stretch Island Bridge 14' ... Permanent
Reach Island Bridge 16' ... Permanent

•Equipped with radio phone, Channels 13 & 16.

TEACHER BACKGROUND - Tide Action on the Beach

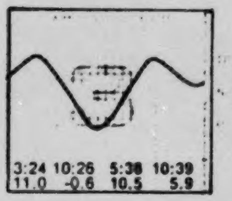
"Tide Action on the Beach" looks at the affect of tides on the beach. Plants and animals living in the intertidal zone face alternate periods of wetting and drying due to the in and out movement of water. The additional stress due to wave action makes the intertidal beach a hard place to live. This exercise provides an introduction to the ways in which animals deal with the environmental conditions found on the beach. In your teaching, emphasize the dynamic nature of the intertidal beach.

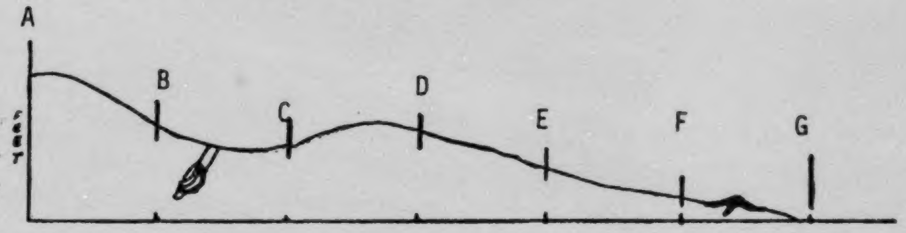
Duplicate the activity pages. One set is recommended per student. This exercise may be performed independently or in small groups. Both approaches have their advantages. Select a technique that is best suited to your class. Alert your students to the fact that the vertical scale on the June 3 marigram (-5 ft. to 15 ft.) is the same as the vertical scale on the beach slope cross section. Each square on the horizontal axis/represents one hour. Plan to spend a few minutes in discussing the activity and in providing the correct answers upon completion of the activity.

KEY

BEACH SLOPE CROSS SECTION

JUNE





1. The tide position of each marker, in feet, above or below zero tide is:

A. about 17 feet above

B. 10 feet above

C. 6 feet above

D. 9 feet above

E. 3 feet above

F. 2 feet below

G. 5 feet below

Answers should agree with above plus or minus 1 foot.

2. The amount of time that each marker is exposed (dry) on June 3rd is:

A. 24 hours
B. 22 hours
C. 8 hours
D. 18 hours
E. 5 hours
F. 0 hours
G. 0 hours

B through E require some estimation, answers should agree plus or minus 1 hour.

3. The total time each marker spends underwater on June 3rd is:

A. 0 hours
B. 2 hours
C. 16 hours
D. 6 hours
E. 19 hours
F. 24 hours
G. 24 hours

Answers should be the difference between 24 hours and the hours determined in (2.) above.

4. The wetting conditions of the markers at 0600 hours are:

A. dry
B. dry
C. underwater
D. dry
E. underwater
F. underwater
G. underwater

5. At 1300 hours, the water line is between markers E and F.

6. You would search for sea anemone at markers F and G because sea anemone prefer to live below the Mean (average) Low Low Water (MLLW) or zero tide line.

7. The sea star could spend about 6 hours at D on June 3rd.

8. The highest marker at which an oyster can survive is marker E which is exposed for about 5 hours on June 3.

9. The designs for the tide gage will vary. The simplest technique would be to plant a tidal staff (a pole with graduations marked upon its surface) at the lowest spot on the beach and visually observe the height of the tides on the staff. Your more creative students will, undoubtably, have other ideas. Reward creativity if the device could record tidal information.

KEY WORDS

marigram

Mean Low Low Water (MLLW)

periodic

zero tide

TIDE ACTION ON THE BEACH

The tides cause the ocean waters to move up and down the beach. The slope of the beach and the height of the tides determine how much beach is subjected to this alternate wetting and drying. This motion and periodic wetting greatly limit the number of animals and plants that live in the intertidal zone. The plants and animals that live in areas affected by the tides have developed special ways to deal with their environment. In this activity you will have a chance to look at some of the changes that occur on the beach due to the tides.

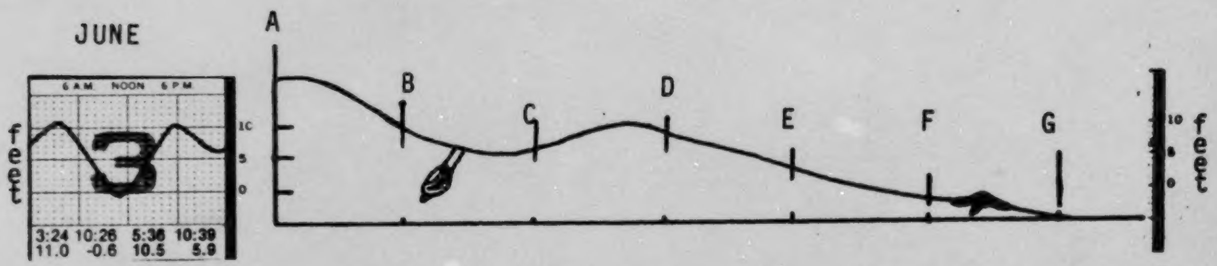
Materials:

beach slope cross section
pencil
straight edge (ruler)

Procedure:

Use the beach slope cross section to answer the following questions.

BEACH SLOPE CROSS SECTION



1. Use the vertical scale to determine the tide position of each marker, in feet, above or below zero tide.

A. ______________________

B. ______________________

C. ______________________

D. ______________________

E. ______________________

F. ______________________

G. ______________________

2. Using the tide calendar marigram, find the amount of time that each marker is exposed (dry) on June 3rd?

A. ______________________ E. ______________________
B. ______________________ F. ______________________
C. ______________________ G. ______________________
D. ______________________

3. What would be the total time each marker spends underwater on June 3rd?

A. ______________________ E. ______________________
B. ______________________ F. ______________________
C. ______________________ G. ______________________
D. ______________________

4. Which markers are underwater and which markers are dry at 0600 hours?

A. ______________________ E. ______________________
B. ______________________ F. ______________________
C. ______________________ G. ______________________
D. ______________________

5. Between what two markers is the water line at 1300 hours?

____

6. Sea anemone prefer to live below the Mean (average) Low Low Water (MLLW) or zero tide line. At what markers would you search for sea anemone?

____

7. The sea star can move up to marker D when the marker is under water. How many hours could the sea star spend at D on June 3rd?

____

8. An oyster can be out of the water for 5 1/2 hours without being hurt. What is the highest marker on the beach at which it can survive on June 3?

---

9. Design a tide gage to record the tides that occur on this beach. Include a drawing of your gage with your explanation of its operation.

TEACHER BACKGROUND - How High's The Water?

"How High's the Water?" provides additional practice in the use of tide tables and reinforces material on the types of tides. The activity also introduces the idea of progression of the tidal crest in a bay or sound.

Duplicate the activity pages including the data found on the tidal difference charts if sufficient Tide Tables are not available. One set of pages per student is recommended.

The activity involves following directions. Anticipate any problems your class may have and prepare the class ahead of time to reduce the likelihood of the problems occurring. There are two parts to this exercise. You may elect to have the students do the first part on one day and the second part on the following day or as homework. For this exercise, students may work individually or in small groups according to your preference. Plan to devote time to a discussion of the exercise and of the questions raised in the text.

KEY

Text Questions

1. The Mean Lower High Water is the long term average of the lower of the two daily high waters.
2. The Mean Higher Low Water is the long term average of the higher of the two daily low waters.

Questions 1 and 2 can be answered by reference to the diagrams in the text. They are designed to make your students think about the various tidal data mentioned. Students often find the many similiar sounding terms confusing. Sometimes an illustration can be helpful in clarifying the various reference terms. You might try something like the following: "Imagine that you watch the tides move the water level on a piling. You cut a notch on a piling at the lower low tide mark each day for several weeks. After this time, you find the midpoint or average of these notches. The midpoint will closely approximate the Mean Lower Low Water (MLLW) mark. This point becomes the zero tide mark and all tide heights and charted water depths are referenced to this level or tide datum. Other data or reference marks can be established in a similiar manner. For example, if the higher high tide levels are notched, the Mean Higher High Water (MHHW) datum is established." Officially, these tide data are established at various localities by automatic recording tide gauges. The diurnal range of a locality is the vertical distance between the two datums described above (i.e. MHHW - MLLW = diurnal range). The diurnal range represents an average value and is a good indicator of the extremes of the higher high and the lower low tides experienced at a particular locality.

Chart - see next page.

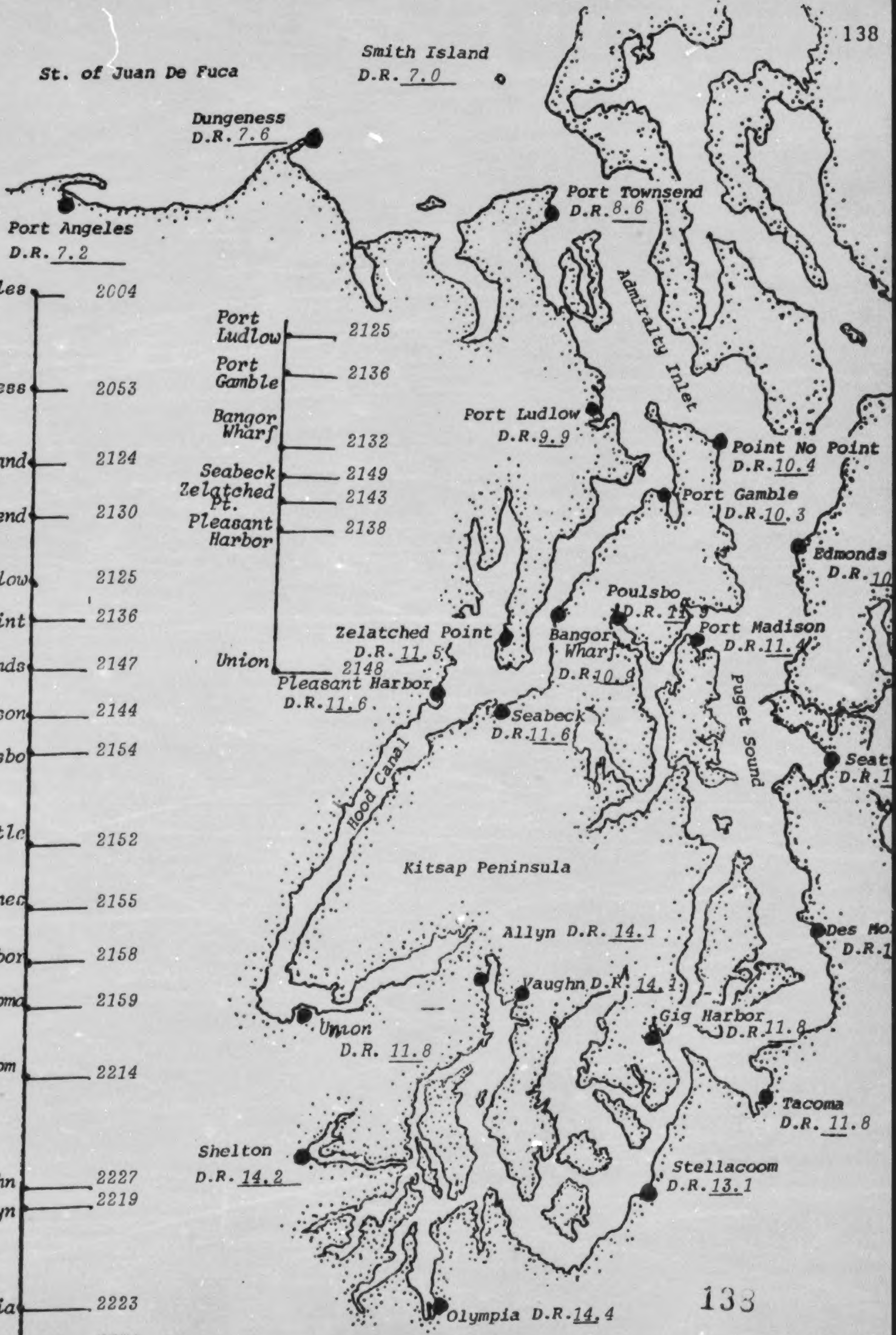
Analysis and Interpretation - Part I

1. The difference in the diurnal ranges between Smith Island (7.0 ft.) and Olympia (14.4 ft.) is 7.4 feet.
2. The difference in the diurnal ranges between Port Ludlow and Union (11.8 ft.) is 1.9 ft.
3. The most likely generalization is that the diurnal range increases as one moves into the Puget Sound or down the Hood Canal from their entrances.

Analysis and Interpretation - Part II

1. Three hours elapse from the passage of the tide at Port Angeles until its arrival at Shelton (Port Angeles to Port Townsend = 0126 hrs) + (Port Townsend to Seattle = 0022 hrs) + (Seattle to Shelton = 0112 hrs) = 0300 hrs).
2. There are several out of sequence sites: Port Ludlow, Port Madison, Poulsbo, and Vaughn in the Puget Sound; and Port Gamble, Pleasant Harbor, Zelatched Point and Union on the Hood Canal. The time of the tidal arrival in the Hood Canal is different than one might expect from casual observation!

KEY


St. of Juan De Fuca
Smith Island
D.R. 7.0
Dungeness
D.R. 7.6
Port Angeles
D.R. 7.2
Port Townsend
D.R. 8.6
Admiralty Inlet
Port Ludlow
D.R. 9.9
Point No Point
D.R. 10.4
Port Gamble
D.R. 10.3
Edmonds
D.R. 10
Poulsbo
D.R. 11.9
Zelatched Point
D.R. 11.5
Bangor Wharf
D.R 10.9
Port Madison
D.R. 11.4
Pleasant Harbor
D.R. 11.6
Seabeck
D.R. 11.6
Puget Sound
Seat
D.R. 1
Hood Canal
Kitsap Peninsula
Allyn D.R. 14.1
Des Mo
D.R. 1
Vaughn D.R. 14.1
Gig Harbor
D.R. 11.8
Union
D.R. 11.8
Tacoma
D.R. 11.8
Shelton
D.R. 14.2
Stellacoom
D.R. 13.1
Olympia D.R. 14.4

Port Angeles	2004
Dungeness	2053
Smith Inland	2124
Port Townsend	2130
Port Ludlow	2125
Point No Point	2136
Edmonds	2147
Port Madison	2144
Poulsbo	2154
Seattle	2152
Des Moines	2155
Gig Harbor	2158
Tacoma	2159
Stellacoom	2214
Vaughn	2227
Allyn	2219
Olympia	2223
Shelton	2304

Port Ludlow	2125
Port Gamble	2136
Bangor Wharf	2132
Seabeck	2149
Zelatched Pt.	2143
Pleasant Harbor	2138
Union	2148

3. Knots = $\frac{\text{N.M.}}{\text{Time}} = \frac{\text{115 N.M.}}{\text{3 hours}}$ = 38.2 knots.

No, a tidal crest speed of 38.2 knots does not imply a tidal current flowing at 38.2 knots. The tidal crest is a moving wave of energy rather than moving water. The water moves at a much slower rate.

4. You would be interested in the velocity of the tidal crest because you would either be riding with it, thereby increasing your speed, or fighting against it, thereby decreasing your speed. You would most likely prefer to begin with the incoming or flood tide to get the benefit of the added speed. It is important to note that the wave forms are moving energy rather than moving water. As such, a boat could not drift with the incoming tidal crest at 38.2 knots.

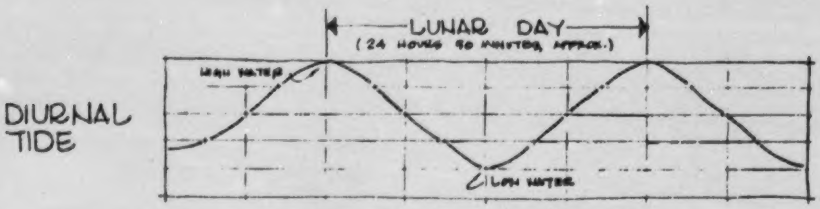
KEY WORDS

chart
consecutive
diurnal
diurnal range
diurnal tides
generalization
high water
higher high water
higher low water
illogical
low water
lower high water
lower low water
Mean Higher High Water
Mean Higher Low Water
Mean Lower High Water
Mean Lower Low Water
mixed tides

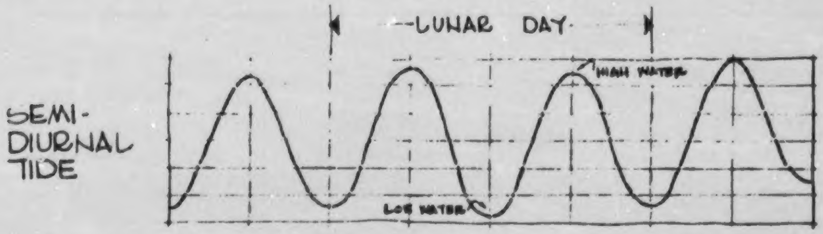
progression
reference
scale
semidiurnal tides
sequence
velocity

HOW HIGH'S THE WATER?

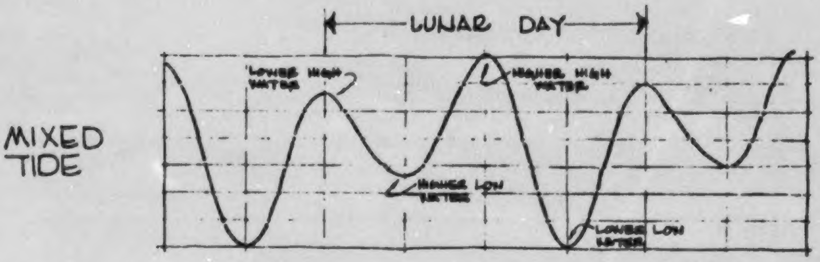
Oceanographers studying tides have found three general types: diurnal, semidiurnal and mixed tides. Each of these three tides has its own characteristics. Areas which have diurnal (daily) tides have only one high water and one low water each day. The tides along the Vietnam-China coast are diurnal.


LUNAR DAY
(24 HOURS 50 MINUTES, APPROX.)
DIURNAL TIDE
HIGH WATER
LOW WATER

Areas with semidiurnal (twice daily) tides have two high waters and two low waters each day with little or no difference between consecutive high or low water heights. Tides along the east coast of the United States, for example, are of the semidurnal type.


LUNAR DAY
SEMI-DIURNAL TIDE
HIGH WATER
LOW WATER

Along the Pacific coast of the United States the tides are mixed tides. Mixed tides have both diurnal and semidiurnal characteristics. There are two high waters and two low waters each day like the semi-diurnal tides but there is a considerable difference between the heights of successive high waters or successive low waters. These differences are called diurnal (daily) inequalities.



Tides have been studied for many years. The data collected now lets us determine long term averages for the high and low tides. Mixed tides, again, have two high waters and two low waters of unequal heights each day. The mean higher high water (MHHW) is the long term average (mean) of the higher of the two daily high waters, similarly, the mean lower low water (MLLW) is the long term average of the lower of the two daily low waters. The diurnal (daily) range of the tide is the difference between the Mean Higher High Water and the Mean Lower Low Water. The diurnal range is an average value that reveals the difference between the higher high tide and the lower low tide each day. This information gives a good idea of the extent of the rise and fall of the tides in any place during the course of a tidal or lunar day.

1. Use the above information to define mean lower high water (MLHW)?
2. Use the above information to define mean higher low water (MHLW)?

In this exercise you will examine the diurnal range and the progression of tides in the Puget Sound, Washington.

Materials:

current tide tables or tidal difference data
lab sheet chart of Puget Sound
ruler with mm divisions

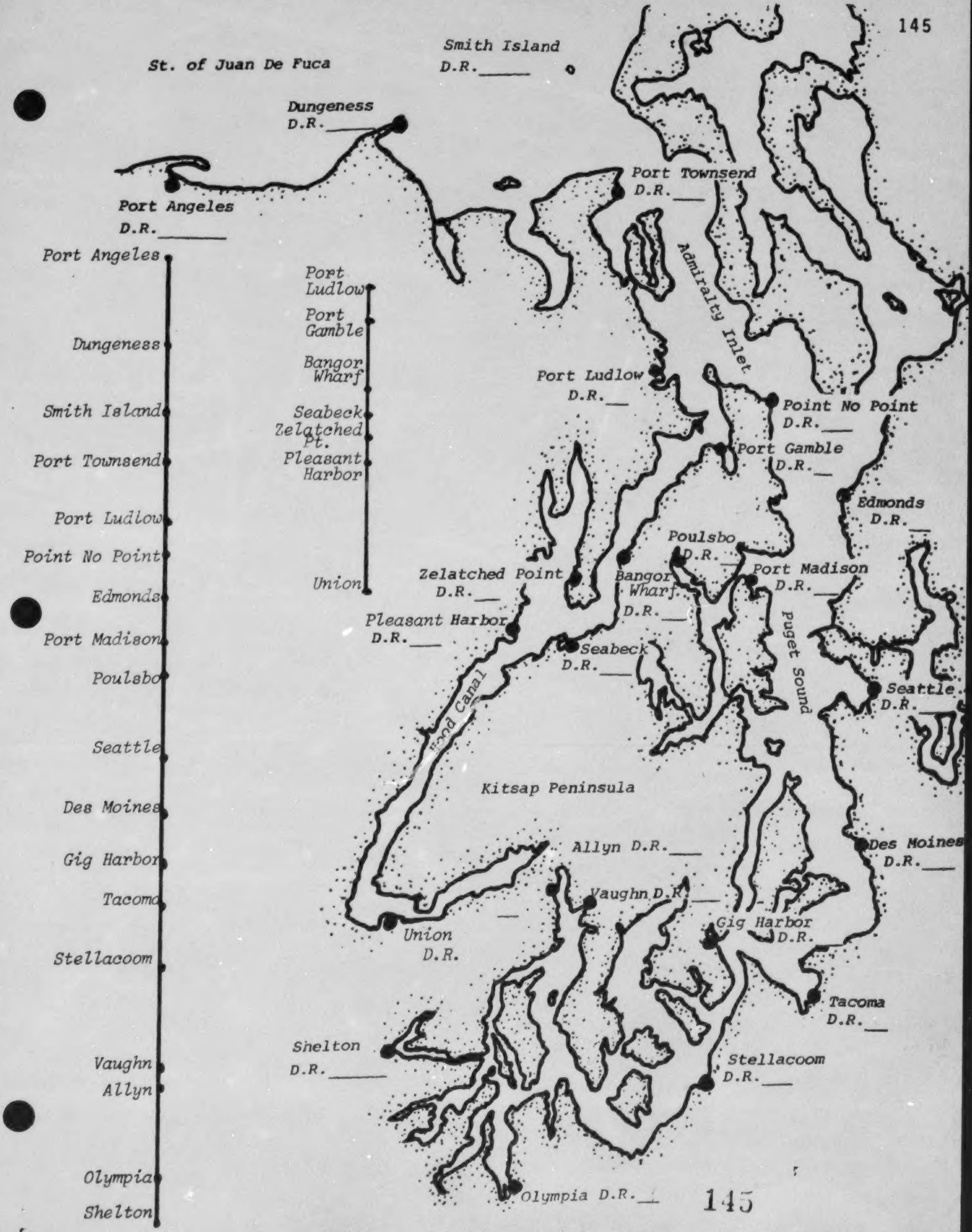
Procedure: Part I

1. Obtain the tidal difference data from the tide tables. Transfer the diurnal range data onto the Puget Sound Chart at the locations identified on the chart. Each location has a blank labeled "D.R." for its diurnal range.
2. For this step, use the two distance lines (Port Angeles to Olympia and Port Ludlow to Union). Using a scale of one foot of diurnal range equals one millimeter (mm), draw a perpendicular line next to the name of each site on the distance line representing the diurnal range for that site. For example, the diurnal range for Port Angeles is 7.2 ft. A vertical line 7.2 mm long should be drawn to Port Angeles.

Analysis and Interpretation :

1. What is the difference in the diurnal ranges between Smith Island (near the mouth of Admiralty Inlet) and Olympia (at the south end of the Puget Sound)?

No.	PLACE	POSITION		DIFFERENCES				RANGES		Mean Tide Level
				Time		Height				
		Lat.	Long.	High water	Low water	High water	Low water	Mean	Diurnal	
		° ′	° ′	h. m.	h. m.	feet	feet	feet	feet	feet
	WASHINGTON—Continued									
	Strait of Juan de Fuca[1]	N.	W.							
	Time meridian, 120°W.									
				on PORT TOWNSEND, p.88						
879	Crescent Bay	48 10	123 44	-2 40	-2 04	*0.80	*0.80	4.1	6.7	4.1
881	Port Angeles	48 07	123 26	-1 32	-1 25	*0.86	*0.86	4.2	7.2	4.4
883	Dungeness	48 10	123 07	-0 53	-0 40	*0.90	*0.90	4.4	7.6	4.7
885	Sequim Bay entrance	48 05	123 03	-0 38	-0 09	*0.94	*0.94	4.8	7.9	4.8
887	Gardiner, Discovery Bay	48 04	122 55	-0 46	-0 19	*0.94	*0.94	4.8	7.9	4.8
889	Smith Island	48 19	122 50	-0 12	-0 27	*0.83	*0.83	4.2	7.0	4.5
891	Point Partridge	48 14	122 46	-0 10	-0 17	*0.92	*0.92	4.5	7.7	4.7
	Admiralty Inlet									
893	Admiralty Head	48 10	122 40	-0 10	+0 18	0.0	0.0	5.2	8.4	5.1
895	PORT TOWNSEND	48 08	122 46	Daily predictions				5.2	8.4	5.1
897	Port Townsend (Point Hudson)	48 07	122 45	-0 10	-0 08	+0.2	+0.1	5.3	8.6	5.2
899	Marrowstone Point	48 06	122 41	+0 03	+0 03	+0.4	0.0	5.6	8.8	5.3
900	Mystery Bay, Marrowstone Island	48 03	122 41	+0 14	+0 46	-0.2	0.0	5.0	8.2	5.0
901	Bush Point	48 02	122 36	+0 33	+1 09	+0.4	0.0	5.6	8.8	5.3
902	Oak Bay	48 01	122 43	+0 09	+0 25	+0.9	+0.1	6.0	9.4	5.6
	Hood Canal			on SEATTLE, p.92						
903	Port Ludlow	47 55	122 41	-0 27	-0 18	*0.88	*0.88	6.4	9.9	5.9
905	Port Gamble	47 52	122 35	-0 16	-0 08	*0.91	*0.91	6.7	10.3	6.1
907	Bangor Wharf	47 45	122 44	-0 20	+0 04	-0.3	0.0	7.3	10.9	6.4
908	Zelatched Point, Dabob Bay	47 43	122 49	-0 09	-0 05	+0.1	+0.1	7.6	11.5	6.7
909	Seabeck	47 38	122 50	-0 03	+0 03	+0.3	+0.1	7.8	11.6	6.8
910	Pleasant Harbor	47 40	122 55	-0 14	+0 01	+0.2	+0.1	7.7	11.6	6.8
911	Union	47 21	123 06	-0 04	+0 10	+0.4	+0.1	7.9	11.8	6.9
	Puget Sound									
912	Hansville	47 55	122 33	-0 07	+0 04	-1.0	-0.1	6.7	10.3	6.1
913	Point No Point	47 55	122 32	-0 16	-0 16	*0.92	*0.92	6.7	10.4	6.1
914	Edmonds	47 49	122 23	-0 05	+0 02	-0.4	0.0	7.2	10.9	6.4
915	Port Madison	47 42	122 32	-0 08	-0 08	+0.1	0.0	7.7	11.4	6.6
917	Poulsbo, Liberty Bay	47 44	122 39	+0 02	+0 08	+0.6	+0.1	8.1	11.9	6.9
919	Brownsville, Port Orchard	47 39	122 37	+0 02	+0 08	+0.4	0.0	8.0	11.7	6.8
921	SEATTLE (Madison St.), Elliott Bay	47 36	122 20	Daily predictions				7.6	11.3	6.6
923	Eighth Ave. S., Duwamish Waterway	47 32	122 19	+0 05	+0 07	-0.1	0.0	7.5	11.1	6.5
925	Port Blakely	47 36	122 30	+0 02	+0 03	+0.2	0.0	7.8	11.5	6.7
927	Pleasant Beach, Rich Passage	47 36	122 32	+0 01	+0 07	+0.2	0.0	7.8	11.5	6.7
929	Bremorton, Port Orchard	47 33	122 38	+0 07	+0 12	+0.4	0.0	8.0	11.7	6.8
931	Tracyton, Dyes Inlet	47 37	122 40	+0 30	+0 56	+1.0	0.0	8.6	12.3	7.1
933	South Colby, Yukon Harbor	47 31	122 32	+0 01	+0 07	+0.3	0.0	7.9	11.6	6.7
935	Des Moines	47 24	122 20	+0 03	+0 09	+0.4	0.0	8.0	11.7	6.8
937	Burton, Quartermaster Harbor	47 23	122 28	+0 07	+0 13	+0.6	0.0	8.2	11.9	6.9
939	Gig Harbor	47 20	122 35	+0 06	+0 14	+0.6	0.0	8.2	11.8	6.9
941	Tacoma, Commencement Bay	47 17	122 25	+0 07	+0 06	+0.5	0.0	8.1	11.8	6.8
943	Arletta, Hale Passage	47 17	122 39	+0 23	+0 36	+1.7	0.0	9.3	13.0	7.4
945	Home, Von Geldern Cove, Carr Inlet	47 16	122 45	+0 27	+0 39	+2.3	+0.2	9.7	13.6	7.8
947	Wauna, Carr Inlet	47 23	122 38	+0 20	+0 36	+1.8	0.0	9.4	13.1	7.5
949	Steilacoom	47 10	122 36	+0 22	+0 35	+1.8	0.0	9.4	13.1	7.5
951	Hyde Point, McNeil Island	47 12	122 39	+0 23	+0 41	+2.1	+0.2	9.5	13.4	7.7
953	Sequalitchew Creek, Nisqually Reach	47 07	122 40	+0 24	+0 42	+2.1	+0.1	9.6	13.4	7.7
955	Longbranch, Filucy Bay	47 13	122 45	+0 26	+0 39	+2.2	+0.1	9.7	13.5	7.7
957	Henderson Inlet	47 09	122 50	+0 27	+0 45	+2.6	+0.2	10.0	14.0	8.0
959	Vaughn, Case Inlet	47 20	122 46	+0 35	+0 47	+2.8	+0.2	10.2	14.1	8.1
961	Allyn, Case Inlet	47 23	122 49	+0 27	+0 46	+2.8	+0.2	10.2	14.1	8.1
963	Walkers Landing, Pickering Passage	47 17	122 56	+0 35	+0 47	+2.9	+0.2	10.3	14.3	8.1
965	Arcadia, Pickering Passage	47 12	122 56	+0 35	+0 54	+3.0	+0.2	10.4	14.4	8.2
967	Shelton, Oakland Bay	47 13	123 05	+1 12	+1 54	+2.8	-0.2	10.6	14.2	7.9
969	Burns Point, Totten Inlet	47 07	123 03	+0 36	+0 54	+3.6	+0.2	11.0	15.0	8.5
971	Rocky Point, Eld Inlet	47 04	123 01	+0 34	+0 52	+3.3	+0.3	10.6	14.7	8.4
973	Dofflemyer Point, Budd Inlet	47 08	122 54	+0 29	+0 47	+3.1	+0.2	10.5	14.4	8.2
975	Olympia, Budd Inlet	47 03	122 54	+0 31	+0 46	+3.1	+0.2	10.5	14.4	8.2


St. of Juan De Fuca
Smith Island D.R.
Dungeness D.R.
Port Angeles D.R.
Port Townsend D.R.
Admiralty Inlet
Port Ludlow D.R.
Point No Point D.R.
Port Gamble D.R.
Edmonds D.R.
Poulsbo D.R.
Port Madison D.R.
Zelatched Point D.R.
Bangor Wharf D.R.
Pleasant Harbor D.R.
Seabeck D.R.
Puget Sound
Seattle D.R.
Hood Canal
Kitsap Peninsula
Allyn D.R.
Des Moines D.R.
Vaughn D.R.
Union D.R.
Gig Harbor D.R.
Tacoma D.R.
Shelton D.R.
Stellacoom D.R.
Olympia D.R.
Port Angeles
Dungeness
Smith Island
Port Townsend
Port Ludlow
Point No Point
Edmonds
Port Madison
Poulsbo
Seattle
Des Moines
Gig Harbor
Tacoma
Stellacoom
Vaughn
Allyn
Olympia
Shelton
Port Ludlow
Port Gamble
Bangor Wharf
Seabeck
Zelatched Pt.
Pleasant Harbor
Union

2. What is the difference in the diurnal ranges between Port Ludlow (at the mouth of Hood Canal) and Union (at the south end of the canal)?

3. State a generalization that describes the changes in diurnal range with location that your data shows. A generalization is a statement that satisfactorily describes the majority of the data.

Procedure - Part II

The highest high tide of May 31, 1979 is 11.4 ft at 2152 hrs at Seattle and 8.3 ft at 2130 hrs at Port Townsend, Washington. In this exercise you will follow the progression in time of a single high tide as it passes Port Angeles, Admiralty Inlet and enters Puget Sound and the Hood Canal. Notice that Port Angeles, Dungeness, Smith Island and Port Townsend are tide sites referenced to Port Townsend Tidal Data. All of the remaining sites are referenced to Seattle Tidal Data.

1. Using the time of the high tide at Port Townsend and Seattle and the time corrections from the Tidal Difference Data, determine the time of arrival at each of the sites shown on your chart. Record the times on your chart next to the scale lines you drew in Part I.

2. Adjacent to the site on your chart, number each Puget Sound site in the order of arrival of the high tide. In your numbering sequence do not include the Hood Canal sites (Port Gamble, Bangor Wharf, Zelatched Point, Seabeck, Pleasant Harbor, and Union).

3. On your chart, letter the Hood Canal sites A to G. Begin with Port Ludlow in sequence of the arrival of the high tide. (All sites referenced to Seattle data).

   Notice that Port Ludlow will have both a number and a letter.

Analysis and Interpretation:

1. How much time elapses from the passage of the high tide at Port Angeles until its arrival at Shelton?

2. Were there any illogical time reversals to this section of the lab? Identify each out of sequence site.

3. The nautical mile (N.M.) distance from Port Angeles to Shelton by water route is 115 N.M. What is the approximate velocity (speed) of the tidal crest.

$$\text{Knots} = \frac{\text{N.M.}}{\text{Time}}$$

   HINT: (Every 6 minutes is 1/10 of an hour). Please show your work.

   Does this velocity represent the speed you would be moving if you were drifting with the tide?

4. As skipper of the troller Richard M., you are entering Admiralty Inlet at Port Townsend bound for Indianola dock at Port Madison. Why might you be interested in the approximate velocity of the tidal crest? When would you want to begin your voyage (incoming tide, outgoing tide, or slack tide)? Please explain your answers.

PHYSICAL FACTORS: Ocean Waves

TEACHER BACKGROUND - Ocean Waves - Three Level Guide

The article "Ocean Waves" by Williard Bascom is difficult reading for many students. This article seems to typify a problem seen in teaching today: we can have articles that cover the material but are too difficult to read or we can have articles that can be read but do not cover the material. The three level guide presented here is one way to solve this seeming dilemma. Three level guides are based on what seems to be the general agreement that comprehension can take place at different levels of cognition. Harold L. Herber has called these levels 1) literal; 2) interpretive; and 3) applied. With the exception of the literal level, each level requires the product of the previous level or levels in order to function.

The literal level of comprehension produces knowledge of what the author said. We all recognize that it is quite possible to identify and even repeat what an author has said without understanding what the author meant by his statements. The interpretive level of comprehension depends upon the reading performed at the literal level but carries the process a step further. At this level the reader derives meaning from what the author has said. The meaning is determined by the way the reader perceives the intratext relationships. The applied level of comprehension takes the product of the literal, (what the author has said) and the interpretive (what the author meant by what he said) and applies it in some practical or theoretical exercise. At this level the reader is using his past experiences and knowledge to produce new ideas which extend beyond those immediately identifiable in the reading selection. It must be born in mind that the level at which a person reads does not reflect upon her intelligence and that the level can change as the material changes. The most advanced engineers and scientists often read at the literal level if they cross into other disciplines. When we read materials from an area with which we have little familiarity, our level of comprehension goes down. Your students are no exception to this observation. The three level guide is a device used to improve a person's comprehension by focusing on important concepts at each of the three levels. The three level guide can be used with any material and is readily constructed. For aid in this regard please see:

> Teaching Reading in the Content Areas. 1970. Harold L. Herber.
> Prentice-Hall, Inc., Englewood Cliffs, New Jersey. 296 pages.

Duplicate the pages of the three level guide. One set is recommended per student. Spend a few minutes describing what is expected of the student. Suggest that the student read the statements in the three level guide before she reads the article. In this way, the statements serve as a preview and your students will be looking for and expecting to see certain concepts. Upon completion of the reading and the three level guide, discuss the guide by reference to the article. It is sometimes helpful to have your students note the page number and paragraph number where they found evidence supporting or refuting the statements in the guide. You can require your students to provide this information or you can offer extra credit for those that include it. Choose the technique that most appeals to you and best fits the needs and skills of your class.

KEY

The correct answers are checked on the three level guide found on the following pages.

OCEAN WAVES

THIS SECTION PULLED DUE TO COPYRIGHT RESTRICTIONS.

KEY

OCEAN WAVES - Three Level Guide

Level I. Directions: Read the following statements carefully. Check those statements that are actually stated or paraphrased in the story. Be ready to explain what is inaccurate about the statements that you do not check.

______ 1. Waves may form from the friction of the wind against the surface but not from air pressure changes.

✓ 2. The size of waves is dependent upon wind speed, the length of time the wind blows, and the distance over which the wind blows.

✓ 3. While a wave may move past a point, the water making up the wave will show no net movement.

✓ 4. Water particles in a wave tend to move in circles.

______ 5. Waves seldom travel more than a few miles.

✓ 6. Waves "break" because the bottom causes the water particles to move past the wave.

______ 7. Tides are very different from waves.

______ 8. The much smaller size of the moon makes it have less of an influence on tides than the sun.

✓ 9. At any one time two high tides occur because of the difference in centrifugal force and gravitational attraction.

✓ 10. Earthquakes and similiar occurrences can cause waves.

✓ 11. Waves are ecologically important.

✓ 12. Waves may keep the upper portion of the intertidal area wet.

KEY

Level II. Directions: The following generalizations may or may not be true based upon what the author implies. Check those statements that you feel can be supported by the story. Be ready to support your opinions.

✓ 1. Climate and topography affect waves in several ways.

____ 2. The contour of the sea bottom affects the shape of the waves traveling above.

✓ 3. Tides can be predicted from knowledge of the positions and orbits of the moon and sun.

____ 4. The height and time of tides is the same from month to month.

✓ 5. Natural disasters can have an influence on waves.

✓ 6. Wave action may influence the types of organisms found on a beach.

✓ 7. Organisms in the tidal zone would be expected to show special adaptations due to their physical environment.

✓ 8. As one proceeds up the beach one might expect to see a change in the species composition present.

LEVEL III. Directions: Read each statement below. Relate the details and your interpretations of the details found in "Ocean Waves" to ideas and experiences you have had which relate to this topic. Check those statements that agree with your experiences and knowledge.

✓ 1. The mechanisms controlling tidal action are complex and interrelated.

✓ 2. While waves may travel thousands of miles, the water particles move only a short distance.

____ 3. All waves are basically similiar.

____ 4. Wave action has little influence on those organisms in the wave zone.

✓ 5. Tidal action places a stress on the organisms which live in the tidal zone due to alternate drying and wetting.

KEY WORDS

adaptations

air pressure

centrifugal force

climate

contour

ecologically

friction

generalizations

gravitational attraction

intertidal

net movement

paraphrased

topography

OCEAN WAVES - Three Level Guide

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____ 2. The size of waves is dependent upon wind speed, the length of time the wind blows, and the distance over which the wind blows.

____ 3. While a wave may move past a point, the water making up the wave will show no net movement.

____ 4. Water particles in a wave tend to move in circles.

____ 5. Waves seldom travel more than a few miles.

____ 6. Waves "break" because the bottom causes the water particles to move past the wave.

____ 7. Tides are very different from waves.

____ 8. The much smaller size of the moon makes it have less of an influence on tides than the sun.

____ 9. At any one time two high tides occur because of the difference in centrifugal force and gravitational attraction.

___ 10. Earthquakes and similar occurrences can cause waves.

___ 11. Waves are ecologically important.

___ 12. Waves may keep the upper portion of the intertidal area wet.

Level II. Directions: The following generalizations may or may not be true based upon what the author implies. Check those statements that you feel can be supported by the story. Be ready to support your opinions.

___ 1. Climate and topography affect waves in several ways.

___ 2. The contour of the sea bottom affects the shape of the waves traveling above.

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___ 5. Tidal action places a stress on the organisms which live in the tidal zone due to alternate drying and wetting.

TEACHER BACKGROUND - One Step Further

Authors, editors and publishers spend a great deal of time, effort, and money to produce the graphics which accompany printed works. The purpose of these graphics is, of course, to clarify and elaborate on the materials of the text. Unfortunately, many students do not use these aids to understanding. This exercise is designed to introduce the student to the utility of the figures included in "Ocean Waves".

Plan to allow time for a discussion of the graphics and to provide the correct answers upon completion of this exercise.

KEY

Cross Section of Ocean Wave

1. The circles represent the orbits (paths) of the water particles in the wave.
2. The wavelength of the wave is the distance between successive crests.
3. As you increase the distance below the surface, the orbital or circular movement of the particles decreases.

Different Trains of Waves

1. When wave trains of different directions and strengths meet in the open sea the result is apparent confusion. The pattern of the waves becomes very complex.

Wave 112 Feet High

1. The information that allowed the height of the 112 foot wave to be recorded was the observation that the crow's nest, the crest of the wave and the horizon all formed a straight line.

Wave Diffraction Diagram

1. Since the vertical lines divided energy into equal units, there are 4 energy units in wave front A.
2. There are four energy units in wave front B.
3. Area A' receives the most energy per foot of water frontage.

Hundred-Foot "Tidal Wave"

1. The minimum height of the tsunami must have been 103 feet since the radio mast which it knocked down was this far above the level of the sea.

Wave Breaks Up

1. A wave breaks up when the swell moves into water shallower than half the wavelength.
2. At number 3, the wave form breaks because the particles of water in the crest have no room to complete their cycles.

KEY WORDS

energy
graphics
negligible
orbital
particle
tsunami
wave diffraction
wavelength
wave trains

ONE STEP FURTHER........

The author of "Ocean Waves", Willard Bascom, provides several drawings. The drawings are designed to help the reader to better understand the points made in the text. Use the graphics in "Ocean Waves" to answer the following questions.

Cross section of Ocean Wave

1. What do the circles in this figure represent?
2. What is the wavelength of a wave?
3. As you increase the distance below the surface, the orbital or circular movement of the particles ______________________.

Different Trains of Waves

1. What happens when wave trains of different directions and strengths meet in the open sea?

Wave 112 Feet High

1. What information was recorded that allowed the height of the 112 foot wave to be recorded?

Wave Diffraction Diagram

1. How many energy units are in wave front A? ________________
2. How many energy units are in wave front B? ________________
3. Which area, A' or B' receives the most energy per foot of water frontage? ____

This kind of information has important practical implications The concentration of energy can cause waves that are higher or lower than would ordinarily be expected. For example, a man-made harbor was built using cement breakwaters. The entrance was located without regard to the shape of the bottom. As a result of this misfortune, it is not uncommon to have four foot waves outside the harbor, negligible waves inside the harbor, and 10 foot waves in the entrance!

Hundred-Foot "Tidal Wave"

1. From the description and pictures, what was the minimum height of the tsunami?

Wave Breaks Up

1. When does a wave break up?

2. What happens at number 3?

---

1. Kinsman, Blair. 1965. Wind Waves - their generation and propagation on the ocean surface. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. page 19.

TEACHER BACKGROUND - More One Step Further.....

"More One Step Further" is designed to provide self-evaluation of the material covered in the article "Ocean Waves". This exercise could also serve as a quiz to culminate the study of"Ocean Waves". Alternatively, it may be used simply as additional reinforcement of the text material.

Duplicate the activity page. One page is recommended per student. Your use of the exercise will determine your presentation. If you use the exercise as reinforcement, students may work independently or in small groups. If you elect to use "More One Step Further..." as a quiz, you will need to provide a copy of the "Wave-Refraction Diagram" from the text for question7, Part II. However you decide to use this activity, plan to spend a few minutes in providing the correct answers and in summarizing the concepts dealt with in the article"Ocean Waves."

KEY

Part I.

1. The author's name is Williard Bascom.
2. Fetch is defined as the extent of open water over which the wind blows to produce waves. This definition is found in the body of the text.
3. Wave period is defined as the time it takes two crests to pass a given point. This definition is found in the caption for the figure entitled "Cross Section of Ocean Wave".
4. The article discusses: f) a, b, c, d.
5. F statistical analysis has not shown the seventh wave to be higher than other waves of a chain.
6. F wave height is the vertical distance between a trough and the succeeding crest.

Part II.

1. Wave length is the distance between two successive crests while wave period is the time it takes two crests to pass a point.
2. Period is the time it takes two successive crests to pass a point. Frequency is the number of waves per given length of time. Period and frequency are mathmatical reciprocals: period = $\frac{\text{time}}{\text{cycles}}$ while frequency = $\frac{\text{cycles}}{\text{time.}}$
3. As a chain of waves approaches a beach the period remains constant.
4. Each wave moves forward with a velocity that corresponds to its length. The energy of the group moves with a velocity only half that of the individual waves.
5. Shallow water waves occur where the water is shallower than half the wavelength of the waves on the surface. For a seismic sea wave to be considered a shallow water wave at the 13,000 foot average depth of the sea, the wavelength would have to be at least 26,000 feet long (ie. twice the depth). Tsunamis have wavelengths of several hundred miles.
6. As a wave group approaches a beach, the period remains unchanged, the height increases, the wave length decreases, the velocity decreases and the direction conforms to the shape of the underwater contours.
7. Sand is less abundant on the headland area (A') than on the beach area (B'). Erosion is most obvious along the headland. Sand is carried from the headland to the beach by the increased wave energy per foot of beach frontage found along A' due to the refraction of the waves. The sand is deposited on the beach area (B') where there is reduced wave energy. The sand, essentially, falls out of the water as the waves loose energy.

KEY WORDS

differentiate

erosion

fetch

seiche

seismic sea wave

shallow water wave

tide

tsunami

velocity

wave chain

wave frequency

wave height

wave period

wave refraction

MORE, ONE STEP FURTHER.........

How well did you read? Answer the questions below to see. If you are unsure of any of the answers, look them up in the text after you have finished all of the other questions.

1. Author's name.
2. Define fetch.
3. Wave period is defined as.
4. The article discusses a) Tsunamis
   b) Waves and wave characteristics
   c) Tides
   d) Seiches
   e) a,b, and c only
   f) a,b,c,d
5. T F Statistical analysis has demonstrated the seventh wave in a series is predictably higher than other waves of a chain.
6. T F Wave height is defined as the height of a crest measured from mean sea height.

....

1. Differentiate between the terms wave length and period.
2. Differentiate between the terms period and frequency.
3. As a chain of waves approaches a beach the __________ remains constant. a) height b) wave length c) velocity d) period e) frequency (use any combination)
4. Mathematically describe the relationship between the velocity of individual waves of a group and the velocity of the energy of the wave group.
5. What would the required wave length of a seismic sea wave be in order for it to be considered a shallow water wave at the 13,000 foot average depth of the sea? What are typical wave lengths for tsunamis?
6. As a wave group approaches a beach, describe what happens to the physical characteristic of wave: a) period; b) height; c) length; d) velocity; and, e) direction.
7. Study carefully the wave refraction diagram on page 8. Assuming sand is the evidence of erosion, discuss the diagram in terms of: a) the presence and/or absence of sand; b) erosion; and, c) wave energy distribution.

TEACHER BACKGROUND - Tsunamis - Three Level Guide

Tsunamis or "Tidal waves" are a terrifying and, yet, fascinating phenomena. Historical records document the great destruction caused by tsunamis. The incredible power of nature is no where more apparent than in these waves. Tsunamis may be started by earthquakes, volcanic eruptions or sea bottom slides. They can travel great distances at rates of several hundred miles per hour to crash on the coast in a wave over a hundred feet tall. The article"Tsunamis" gives both the historical background of and scientific explanation for this interesting phenomenon.

Duplicate the three level guide. One is recommended per student. This activity is best accomplished individually. The educational rationale for the three level guide is found in the Teacher Background section for "Ocean Waves - Three Level Guide". Please read the rationale if you have not used the three level guide approach before. Spend a few minutes describing what is expected of the student. Suggest that the student read the statements in the three level guide before she reads the article. In this way, the statements serve as a preview and your students will be looking for and expecting to see certain concepts. Upon completion of the reading and the three level guide, discuss the guide by reference to the article. It is sometimes helpful to have your students note the page number and paragraph number where they found evidence supporting or refuting the statements in the guide. You can require your students to provide this information or you can offer extra credit for those that include it. Choose the technique that most appeals to you and best fits the needs and skills of your class.

KEY

The correct answers are checked on the three level guide found on the following page.

KEY

TSUNAMIS - Three Level Guide

Level I. Directions: Read the statements carefully. Then as you read the selection, refer back to the statements in the guide and check those statements that are actually stated or paraphrased in the selection. Be ready to explain what is inaccurate about the statements that you do not check.

_____1. Tsunamis are caused by the tidal forces of the moon and sea.

✓ 2. Tsunamis have been responsible for some of the worst disasters in human history.

✓ 3. Sea bottom slides, earthquakes and volcanic eruptions can cause tsunamis.

✓ 4. Tsunamis are shallow compared to their length and so are hardly detectable in the open sea even though they may be traveling in deep waters at a speed of 500 miles per hour.

_____5. The first wave of a tsunami is the highest.

✓ 6. Tsunamis can now be detected and human loss decreased due to a tsunami-warning system developed in 1946.

Level II. Directions: The following statements may or may not be true, based on what the author implies. Check those statements that you feel can be supported by the story. Be ready to support your opinions.

✓ 1. The beach is the worst place to be when a tsunami hits.

_____2. People in ships on the open ocean are in great danger during a tsunami.

_____3. Concrete buildings are safe from the affects of tsunamis.

Level III. Directions: Read each statement below. Relate the details and your interpretations drawn from the selection to ideas and experiences you have had in reference to this topic. Check the statements you agree with.

____1. Since the San Francisco Bay Area is a seismically active area, they are more likely to have tsunamis.

____2. To protect people from tsunamis, buildings should not be allowed within a quarter of a mile of the shoreline.

KEY WORDS

interpretations

paraphrased

seismically active

tidal forces

tsunamis

TSUNAMIS

by JOSEPH BERNSTEIN

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TSUNAMIS

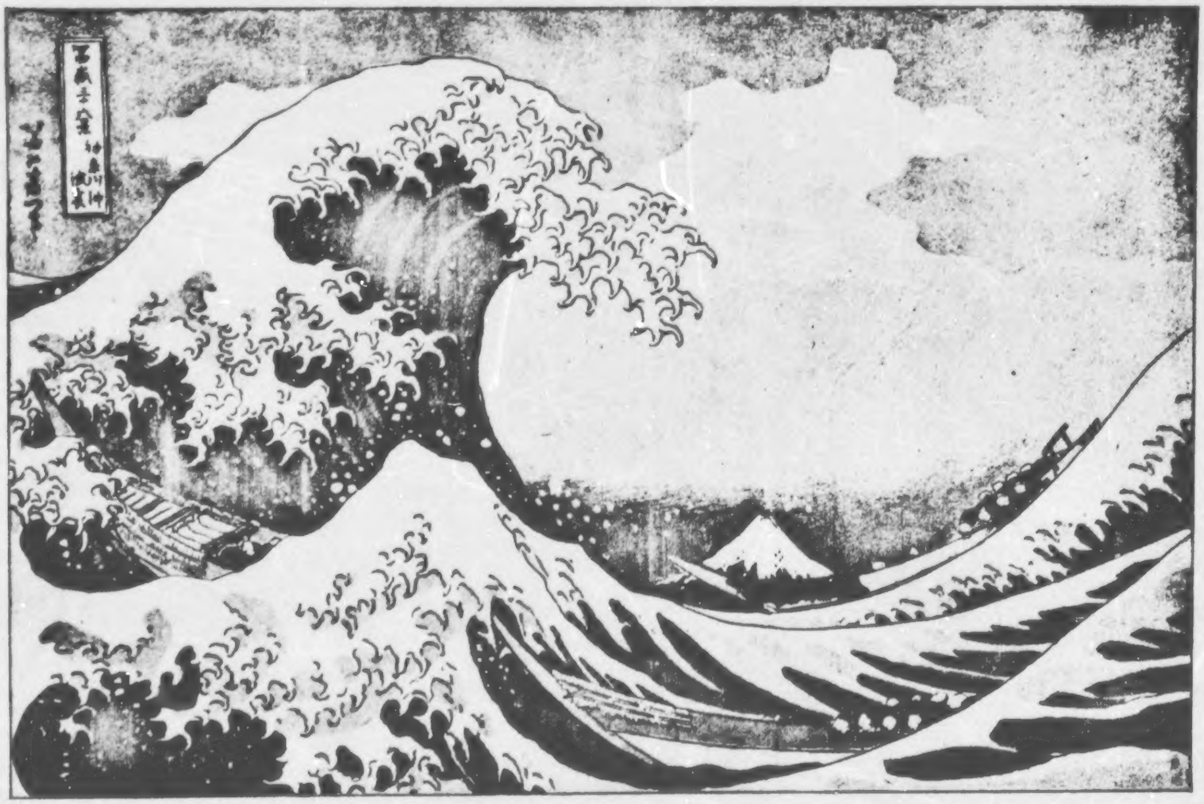
They are huge waves that crash suddenly into a coast. Often called tidal waves, they have nothing to do with tides. They are created by underwater earthquakes or volcanic explosions

by Joseph Bernstein

On the morning of April 1, 1946, residents of the Hawaiian Islands awoke to an astonishing scene. In the town of Hilo almost every house on the side of the main street facing Hilo Bay was smashed against the buildings on the other side. At the Wailuku River a steel span of the railroad bridge had been torn from its foundations and tossed 300 yards upstream. Heavy masses of coral, up to four feet wide, were strewn on the beaches. Enormous sections of rock, weighing several tons, had been wrenched from the bottom of the sea and thrown onto reefs. Houses were overturned, railroad tracks ripped from their roadbeds, coastal highways buried, beaches washed away. The waters off the islands were dotted with floating houses, debris and people. The catastrophe, stealing upon Hawaii suddenly and totally unexpectedly, cost the islands 159 lives and $25 million in property damage.

Its cause was the phenomenon commonly known as a "tidal wave," though it has nothing to do with the tidal forces of the moon or sun. More than 2,000 miles from the Hawaiian Islands, somewhere in the Aleutians, the sea bottom had shifted. The disturbance had generated waves which moved swiftly but almost imperceptibly across the ocean and piled up with fantastic force on the Hawaiian coast.

Scientists have generally adopted the name "tsunami," from the Japanese, for the misnamed tidal wave. It ranks among the most terrifying phenomena known



TSUNAMI near the coast of Japan was depicted by Hokusai, great 19th-century Japanese print maker. The title of the print (*upper left*) is approximately translated: "The crest of the great wave off Kanagawa." In the background is the smooth cone of Fujiyama.

to man and has been responsible for some of the worst disasters in human history. What made the 1946 tsunami especially notable was that a number of oceanographers happened to be in the Pacific (in connection with the Bikini atomic bomb test) and were able to observe it at first hand. It became the most thoroughly investigated tsunami in history, and from it came the development of an effective new warning system by the U. S. Coast and Geodetic Survey.

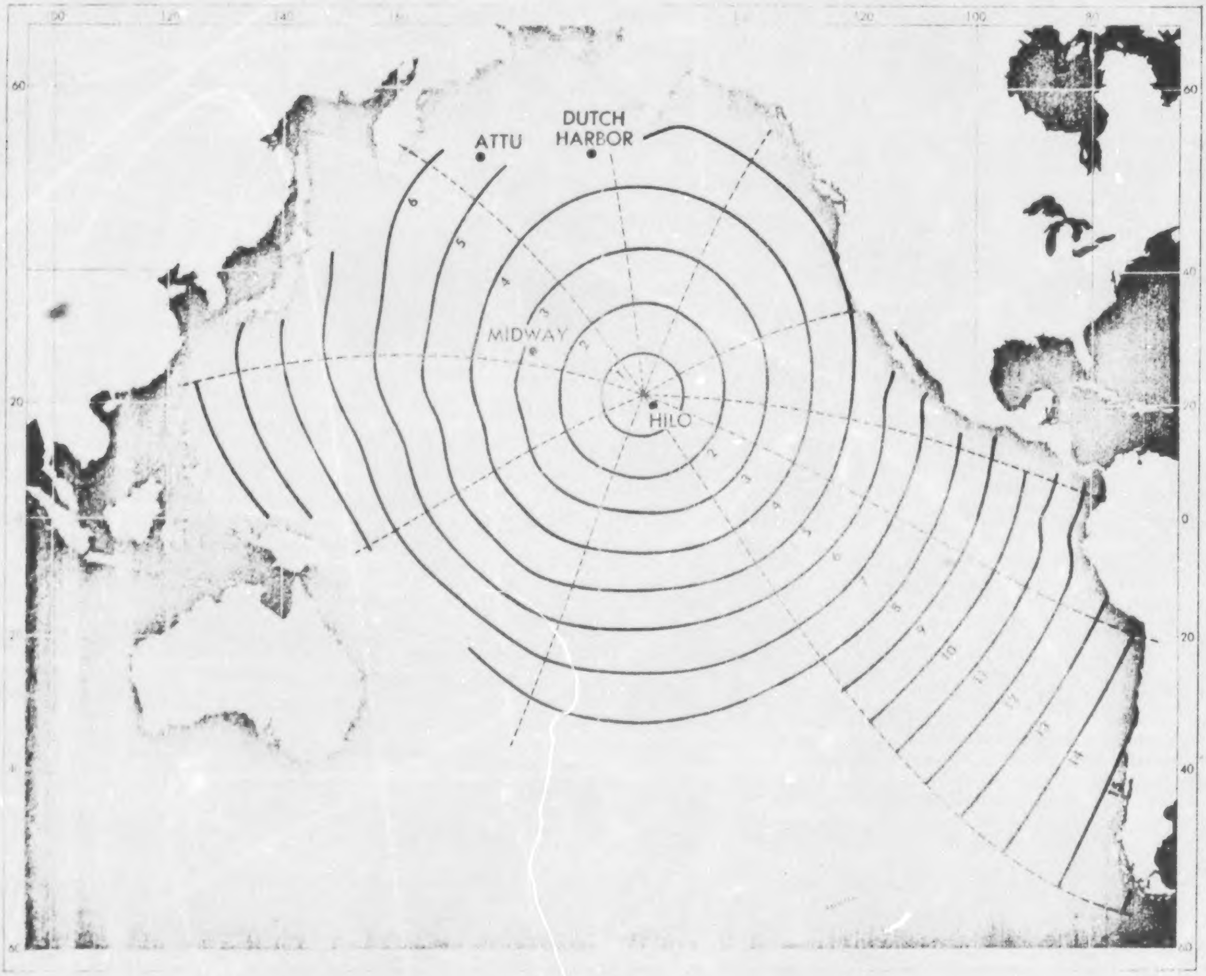
A tsunami may be started by a sea-bottom slide, an earthquake or a volcanic eruption. The most infamous of all was launched by the explosion of the island of Krakatoa in 1883; it raced across the Pacific at 300 miles an hour, devastated the coasts of Java and Sumatra with waves 100 to 130 feet high, and pounded the shore as far away as San Francisco.

The ancient Greeks recorded several catastrophic inundations by huge waves. Whether or not Plato's tale of the lost continent of Atlantis is true, skeptics concede that the myth may have some foundation in a great tsunami of ancient times. Indeed, a tremendously destructive tsunami that arose in the Arabian Sea in 1945 has even revived the interest of geologists and archaeologists in the Biblical story of the Flood.

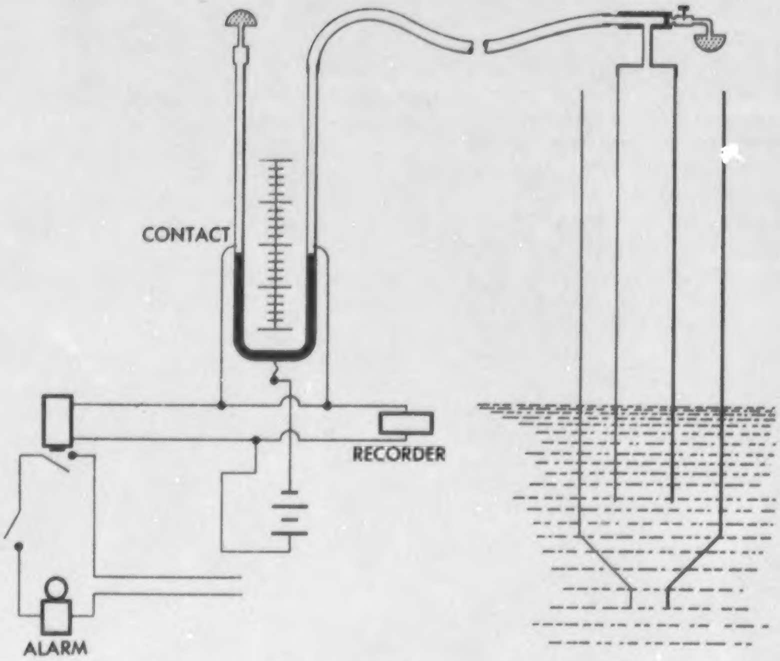
One of the most damaging tsunamis on record followed the famous Lisbon earthquake of November 1, 1755; its waves persisted for a week and were felt as far away as the English coast. Tsunamis are rare, however, in the Atlantic Ocean; they are far more common in the Pacific. Japan has had 15 destructive ones (eight of them disastrous) since 1596. The Hawaiian Islands are struck severely an average of once every 25 years.

In 1707 an earthquake in Japan generated waves so huge that they piled into the Inland Sea; one wave swamped more than 1,000 ships and boats in Osaka Bay. A tsunami in the Hawaiian Islands in 1869 washed away an entire town (Ponoluu), leaving only two forlorn trees standing where the community had been. In 1896 a Japanese tsunami killed 27,000 people and swept away 10,000 homes.

The dimensions of these waves dwarf all our usual standards of measurement. An ordinary sea wave is rarely more than a few hundred feet long from crest to crest—no longer than 320 feet in the Atlantic or 1,000 feet in the Pacific. But a tsunami often extends more than 100 miles and sometimes as much as 600 miles from crest to crest. While a wind wave never travels at more than about 60 miles per hour, the velocity of a tsunami in the open sea must be reckoned in hundreds of miles per hour. The greater the depth of the water,



TIME PLOT of tsunamis endangering the Hawaiian Islands may be made from this chart. When the earthquake epicenter is plotted on it, the circles indicate the time in hours for the seismic sea wave to reach Hawaii. Locations of seismic sea-wave detectors in the warning system are named on the chart. Seismographs are located in Japan, Alaska, Guam and along the coast of North and South America.



DETECTOR signals the occurrence of a seismic sea wave. An air column in the inner tube at right rises and falls with the tide. A wave of sufficient magnitude increases the air pressure until the mercury in the U-tube is forced around, closing a circuit and sounding an alarm.

the greater is the speed of the wave; Lagrange's law says that its velocity is equal to the square root of the product of the depth times the acceleration due to gravity. In the deep waters of the Pacific these waves reach a speed of 500 miles per hour.

Tsunamis are so shallow in comparison with their length that in the open ocean they are hardly detectable. Their amplitude sometimes is as little as two feet from trough to crest. Usually it is only when they approach shallow water or the shore that they build up to their terrifying heights. On the fateful day in 1896 when the great waves approached Japan, fishermen at sea noticed no unusual swells. Not until they sailed home at the end of the day, through a sea strewn with bodies and the wreckage of houses, were they aware of what had happened. The seemingly quiet ocean had crashed a wall of water from 10 to 100 feet high upon beaches crowded with bathers, drowning thousands of them and flattening villages along the shore.

The giant waves are more dangerous on flat shores than on steep ones. They usually range from 20 to 60 feet in height, but when they pour into a V-shaped inlet or harbor they may rise to mountainous proportions.

Generally the first salvo of a tsunami is a rather sharp swell, not different enough from an ordinary wave to alarm casual observers. This is followed by a tremendous suck of water away from the shore as the first great trough arrives. Reefs are left high and dry, and the beaches are covered with stranded fish. At Hilo large numbers of people ran out to inspect the amazing spectacle of the denuded beach. Many of them paid for their curiosity with their lives, for some minutes later the first giant wave roared over the shore. After an earthquake in Japan in 1793 people on the coast at Tugaru were so terrified by the extraordinary ebbing of the sea that they scurried to higher ground. When a second quake came, they dashed back to the beach, fearing that they might be buried under landslides. Just as they reached the shore, the first huge wave crashed upon them.

A tsunami is not a single wave but a series. The waves are separated by intervals of 15 minutes to an hour or more (because of their great length), and this has often lulled people into thinking after the first great wave has crashed that it is all over. The waves may keep coming for many hours. Usually the third to the eighth waves in the series are the biggest.

Among the observers of the 1946 tsunami at Hilo was Francis P. Shepard of the Scripps Institution of Oceanography, one of the world's foremost marine geologists. He was able to make a detailed inspection of the waves. Their onrush and retreat, he reported, was accompanied by a great hissing, roaring and rattling. The third and fourth waves seemed to be the highest. On some of the islands' beaches the waves came in gently; they were steepest on the shores facing the direction of the seaquake from which the waves had come. In Hilo Bay they were from 21 to 26 feet high. The highest waves, 55 feet, occurred at Pololu Valley.

Scientists and fishermen have occasionally seen strange by-products of the phenomenon. During a 1933 tsunami in Japan the sea glowed brilliantly at night. The luminosity of the water is now believed to have been caused by the stimulation of vast numbers of the luminescent organism *Noctiluca miliaris* by the turbulence of the sea. Japanese fishermen have sometimes observed that sardines hauled up in their nets during a tsunami have enormously swollen stomachs; the fish have swallowed vast numbers of bottom-living diatoms, raised to the surface by the disturbance. The waves of a 1923 tsunami in Sagami Bay brought to the surface and battered to death huge numbers of fishes that normally live at a depth of 3,000 feet. Gratified fishermen hauled them in by the thousands.

The tsunami-warning system developed since the 1946 disaster in Hawaii relies mainly on a simple and ingenious instrument devised by Commander C. K. Green of the Coast and Geodetic Survey staff. It consists of a series of pipes and a pressure-measuring chamber which record the rise and fall of the water surface. Ordinary water movements, such as wind waves and tides, are disregarded. But when waves with a period of between 10 and 40 minutes begin to roll over the ocean, they set in motion a corresponding oscillation in a column of mercury which closes an electric circuit. This in turn sets off an alarm, notifying the observers at the station that a tsunami is in progress. Such equipment has been installed at Hilo, Midway, Attu and Dutch Harbor. The moment the alarm goes off, information is immediately forwarded to Honolulu, which is the center of the warning system.

This center also receives prompt reports on earthquakes from four Coast Survey stations in the Pacific which are equipped with seismographs. Its staff makes a preliminary determination of the epicenter of the quake and alerts tide stations near the epicenter for a tsunami. By means of charts showing wave-travel times and depths in the ocean at various locations, it is possible to estimate the rate of approach and probable time of arrival at Hawaii of a tsunami getting under way at any spot in the Pacific. The civil and military authorities are then advised of the danger, and they issue warnings and take all necessary protective steps. All of these activities are geared to a top-priority communication system, and practice tests have been held to assure that everything will work smoothly.

Since the 1946 disaster there have been 15 tsunamis in the Pacific, but only one was of any consequence. On November 4, 1952, an earthquake occurred under the sea off the Kamchatka Peninsula. At 17:07 that afternoon (Greenwich time) the shock was recorded by the seismograph alarm in Honolulu. The warning system immediately went into action. Within about an hour, with the help of reports from seismic stations in Alaska, Arizona and California, the quake's epicenter was placed at 51 degrees North latitude and 158 degrees East longitude. While accounts of the progress of the tsunami came in from various points in the Pacific (Midway reported it was covered with nine feet of water), the Hawaiian station made its calculations and notified the military services and the police that the first big wave would arrive at Honolulu at 23:30 Greenwich time.

It turned out that the waves were not so high as in 1946. They hurled a cement barge against a freighter in Honolulu Harbor, knocked down telephone lines, marooned automobiles, flooded lawns, killed six cows. But not a single human life was lost, and property damage in the Hawaiian Islands did not exceed $800,000. There is little doubt that the warning system saved lives and reduced the damage.

But it is plain that a warning system, however efficient, is not enough. In the vulnerable areas of the Pacific there should be restrictions against building homes on exposed coasts, or at least a requirement that they be either raised off the ground or anchored strongly against waves.

The Author

JOSEPH BERNSTEIN was plunged into the subject of tidal waves only recently, when he took a job as oceanographer with the U. S. Navy Hydrographic Office after a very different career. He had been a social worker and expert on labor relations—Brooklyn field office supervisor of the U. S. Department of Labor Wage and Hour Division. But he has an M.A. in zoology from Columbia University and has long been a writer and reader in many fields of science; when recent appropriations cuts eliminated his Department of Labor job, he was delighted at the opportunity to turn to oceanography.

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CREDIT—PAGE 3: METROPOLITAN MUSEUM OF ART

TSUNAMIS - Three Level Guide

Level I. Directions: Read the statements carefully. Then as you read the selection, refer back to the statements in the guide and check those statements that are actually stated or paraphrased in the selection. Be ready to explain what is inaccurate about the statements that you do not check.

_____1. Tsunamis are caused by the tidal forces of the moon and sea.

_____2. Tsunamis have been responsible for some of the worst disasters in human history.

_____3. Sea bottom slides, earthquakes and volcanic eruptions can cause Tsunamis.

_____4. Tsunamis are shallow compared to their length and so are hardly detectable in the open sea even though they may be traveling in deep waters at a speed of 500 miles per hour.

_____5. The first wave of a Tsunami is the highest.

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Level II. Directions: The following statements may or may not be true, based on what the author implies. Check those statements that you feel can be supported by the story. Be ready to support your opinions.

_____1. The beach is the worst place to be when a Tsunami hits.

_____2. People in ships on the open ocean are in great danger during a Tsunami.

_____3. Concrete buildings are safe from the affects of Tsunamis.

Level III. Directions: Read each statement below. Relate the details and your interpretations drawn from the selection to ideas and experiences you've had in reference to this topic. Check the statements you agree with.

_____1. Since the San Francisco Bay Area is a seismically active area, they are more likely to have Tsunamis.

_____2. To protect people from Tsunamis, buildings should not be allowed within a quarter of a mile of the shoreline.

PHYSICAL FACTORS: Ocean Currents

TEACHER BACKGROUND - Ocean Currents

The sun is a giant motor driving the waters of the oceans in huge relatively well defined currents. The water masses move as a result of the winds or because of differences in temperature between surface layers and lower water layers. Wind driven circulation primarily moves the water masses in a horizontal direction. Temperature differences account for vertical movements of water as well as for some horizontal movement. The persistent movements of ocean waters account for the fact that sea waters are remarkably well mixed and similiar in spite of the vastly different inputs of freshwater and silt found in different parts of the world.

Duplicate the text materials. One set is recommended per student. This activity lends itself well to individual work. Currents tend to be somewhat abstract to students. The text makes an effort to relate currents to important events. You should continue this vein in your teaching. Supplement the text with audio visual aids, if possible. Provide an opportunity to discuss the concepts stressed in the text and to provide answers to the text questions.

KEY - text questions

1. Current information would have predicted that icebergs might be in the sea lanes in which the Titanic was traveling. Additional precautions could then have been taken to avoid collision.
2. The two principal driving forces behind the currents are: a. the wind; and, b. differences in the densities of sea water in different areas.
3. Hot water from power plants will tend to float on the layers of colder water below. It is not likely that these outflows in their present numbers would have much of an effect on global ocean currents. They may, however, have a rather sizeable influence on local conditions.

4. Gyres are large circular patterns of water movement.
5. Upwelling brings waters rich in oxygen and minerals to the surface. These waters provide for the abundant growth of microscopic plants and animals. These organisms provide the base for a food chain that can support many different species. Upwelling, then, increases the numbers and variety in the area affected.

KEY WORDS

anthropologists
convection
currents
density (ies)
equator
friction
Gulf Stream Current
gyres
liner
maritime
Northern Hemisphere
poles
salinity
Southern Hemisphere
temperature
upwelling
waves

OCEAN CURRENTS

The waters of the sea are always in motion. The waves of the surface represent energy flowing through the water. The water itself is also moving, although slower than the waves. How are these ocean currents, the great rivers of water flowing in the seas, important to man?

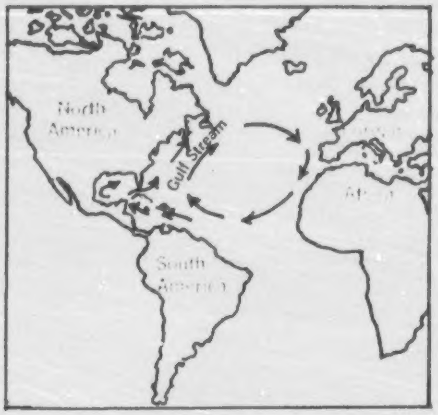
The warning came from the ship, Mesaba, "Ice report latitude 42 N to 41.25 N longitude 49 to 50.30 W have sighted heavy pack ice number of large bergs and field ice weather good and clear." All ships in the area heard the warning on the cold night of April 14, 1912.

On board the ocean liner Carpathia, radioman Tom Cottam listened to the call at 11:40 P.M.: SOS SOS CQD CQD". Cottam replied and the message continued: "Have struck iceberg come to our assistance at once position latitude 41.46 N longitude 50.14 have informed bridge." The unsinkable liner, Titanic, was sinking. In the next three hours a tragic page of maritime history was written. The light of dawn would find only 705 of the 2208 passengers and crew living. How could knowledge of ocean currents, have helped avoid this tragedy? Ocean currents move ice as well as water. Understanding current behaviors will help us to avoid similar tragedies in the future.

1. **Weather conditions in the spring of 1912 indicated that icebergs would be forming. How could this information coupled with information about the direction and speed of current flow have helped prevent the sinking of the Titanic?**

The existence of currents has been known for a long time. In the late 1700's Benjamin Franklin wondered why American sailing ships took about two weeks less to cross the Atlantic than similar English ships.

Franklin discovered that American captains were taking advantage of a current running eastward across the North Atlantic at about three miles an hour. Returning from England, the American ships sailed to avoid the current as much as possible. Franklin named this current the "Gulf Stream". Today we know that the Gulf Stream is but one of many ocean currents.



The Gulf Stream

What causes the ocean currents we see? The currents appear to be caused by a combination of factors. The main driving force of the currents comes from the wind. The wind blows across the surface of the water causing the water particles to move from the friction. The second principal driving force comes from differences in the densities of sea water in different areas. Wind forces are readily seen. Can we see the forces due to density differences?

2. What are the two pincipal driving forces behind the currents?

   a. ____

   b. ____

If you have ever dived into a swimming pool and felt colder water at the bottom, you will have little trouble believing that cold water is heavier than warm water and tends to sink. How can this observation help explain some of the currents? Let's look at the earth's position in relation to the rays from the sun.

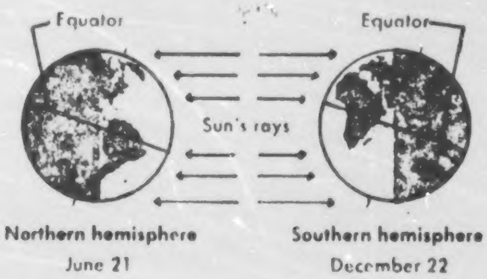


figure 1-2

Even though the earth is slightly inclined from the vertical, it isn't hard to see that the most direct rays from the sun strike the earth near the equator. These direct rays produce more heat. Therefore, the waters near the equator will be warmer than the waters nearer the poles. These differences in temperature cause water to move, they cause currents. Temperature caused currents are called convection currents.

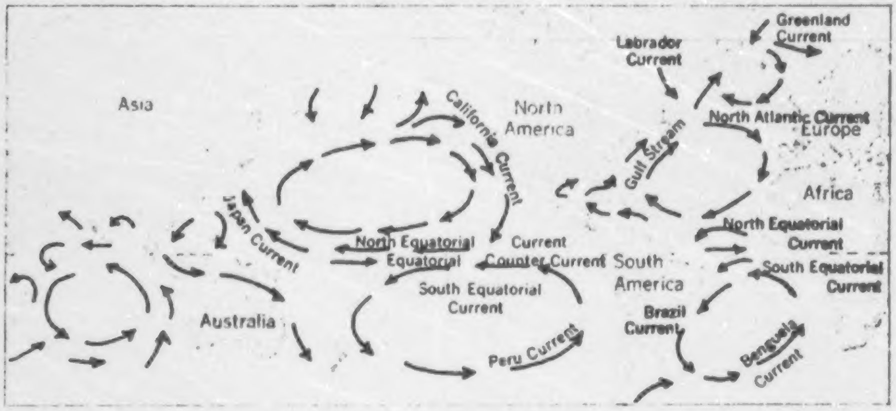
Temperature is not the only thing that can change the density of water. The addition of salt makes water more dense. The sea is relatively uniform in salinity (salt concentration). But we find local differences which can help cause currents. For example, the ice caps around the poles are frozen fresh water. As icebergs melt, they tend to dilute the salt water. This water tends to stay near the surface. Conversely as icebergs form, the surrounding water becomes very cold and full of salt. This cold, dense water sinks and travels in bottom currents all the way to the equator. Differences in density due to salinity, then, can also cause currents.

3. Power plants often discharge hot, fresh water into the ocean. Because the water is hot, it will tend to (a) sink (b) float.

   Is it likely these outflows would have much of an effect on world ocean currents?

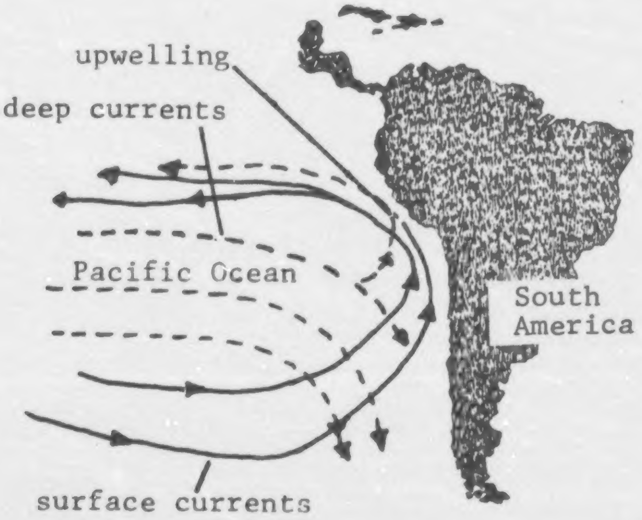
Look at the map of the ocean currents of the world. How do the currents move? The major currents flow in large circular patterns or gyres (jy - urz). These gyres tend to stay in either the Northern hemisphere or in the Southern hemisphere. If you look carefully you will notice that the currents move in different directions in the two hemispheres: clockwise north of the equator and counter-clockwise south of the equator. Currents that flow away from the equator are warm currents. Those that flow away from the poles and toward the equator carry cold arctic waters.

OCEAN CURRENTS


Greenland Current
Labrador Current
Asia
California Current
North America
North Atlantic Current
Europe
Gulf Stream
Africa
Japan Current
North Equatorial
Equatorial
Current
Counter Current
South America
North Equatorial Current
South Equatorial Current
South Equatorial Current
Australia
Brazil Current
Peru Current
Benguela Current

4. What are gyres?

Surface currents have been studied since Benjamin Franklin's day. The study of deep water currents is much more recent and incomplete. Deep water currents run below the surface currents. The surface currents move water to a depth of about 2,000 feet. Deep currents move waters from about 2,000 feet deep to about 10,000 feet deep. These cold deep waters are often rich in oxygen and nutrients necessary for the growth of microscopic plants and animals. Sometimes this deep water surfaces in a movement known as upwelling. Upwelling provides basic food for fish and the fish populations tend to thrive in these areas. A major upwelling occurs on the Pacific Coast of South America. The Peruvian anchovy business depends upon this upwelling for success.



Currents and Upwelling on the Coast of South America

5. How does upwelling affect marine life?

How else have the currents influenced man? Our climate is affected by the currents. The cool California current flows toward the equator along the Pacific coast. The warm Gulf Stream Current flows northward to about the New England States along the Atlantic coast. If we looked at two locations at the same latitude but on the opposite coasts, we would find that the location on the east coast tended to be slightly warmer due to the effect of the Gulf Stream Current. Currents were also important in the past. Sailing ships used their knowledge of surface currents. Some *anthropologists* who study past cultures believe that ancient peoples traveled across the oceans using the currents to carry them along. For an interesting true adventure story of an expedition to duplicate these ancient travels you might want to read *Kon-Tiki* by Thor Heyerdahl. Knowledge of surface and deep currents will become more important as we seek to further exploit the resources of the oceans.

6. The New England states and Nova Soctia, Canada have very severe winters. Use the map of ocean currents to help explain this observation.

TEACHER BACKGROUND - Drifting with the R/V Yaquina

"Drifting with the R/V Yaquina"gives your students a chance to use actual data gathered by a research vessel from Oregon State University to further their understanding of ocean currents.

Duplicate the pages. One set is recommended per student. This activity can be done individually but much is to be gained by having your students work in small groups. Your particular class will dictate the approach you use. A discussion of longitude and latitude will help clarify the data. Watch to see that your students understand how to transfer the plotted lines to the latitude axis to determine the length of the lines. Provide whatever help your students require. Plan to alot time for discussion of the results and interpretation sections.

KEY

See map which follows for correct plotting of data. A Completed data chart is also included.

1. Bottle Number 7. (20764) traveled the farthest (354.8 kilometers).
2. Bottle Number 6 (20869) had the slowest speed (.046 knots)
3. Bottle Number 7 (20764) had the greatest change in latitude. The change was 2 degrees 32 minutes or 152 nautical miles.
4. The data does not support this generalization. For instance, bottle Number 3 (21722) traveled much further north than bottles released further at sea. The distance out and the distance in latitude covered are not a perfect correlation.
5. No, undoubtably drift bottles move much further than our straight line measurements would indicate.

6. Electronic radio transmitters will permit us to actually track the drift bottles to get an idea of the actual course followed. This will improve our knowledge of the currents by letting us trace smaller currents.
7. The distance from shore at which the bottles are released definitely has an effect on where they are found. Out to about 126 degrees of longitude the bottles travel north. At 126 degrees to 127 degrees of longitude they may go north or south. Farther out than 127 degrees the bottles go north again.
8. No. See the answer to number 7.
9. Data gathered at other times of the year might be very different. For example, the warm Davidson current which flows northward along the coast occurs only in late fall and winter when the wind frequently comes from a southerly direction. Changes in summer and winter temperatures and wind patterns can have an effect on the current patterns.

KEY WORDS

axis

currents

degree

drift bottle

equator

generalization

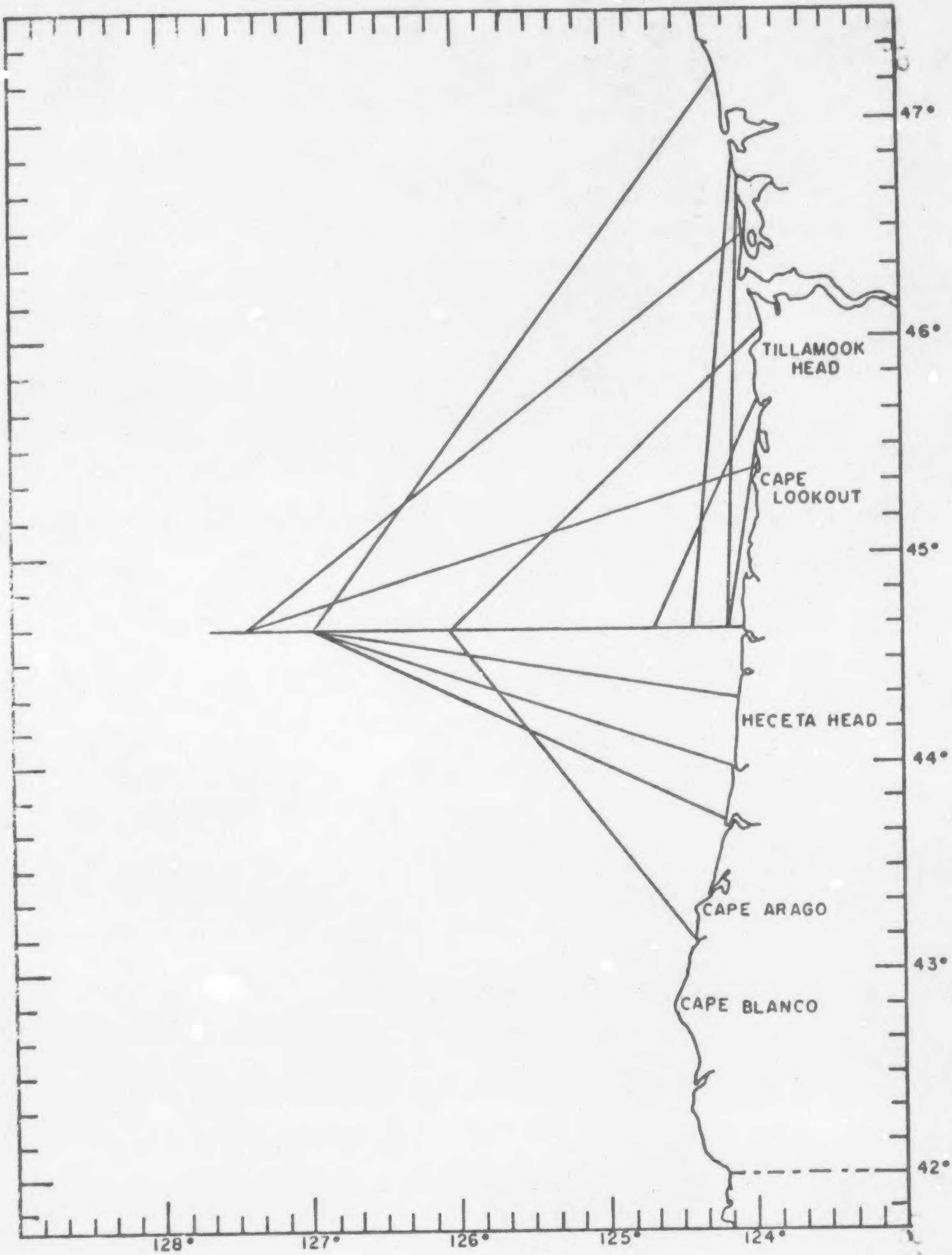
knots

latitude

longitude

nautical miles

vertical


TILLAMOOK HEAD
CAPE LOOKOUT
HECETA HEAD
CAPE ARAGO
CAPE BLANCO
47°
46°
45°
44°
43°
42°
128°
127°
126°
125°
124°

KEY

DRIFT BOTTLE DATA SHEET

Cruise Y7011B

November 19-21, 1970

	Bottle No.	Release position Lat N	Release position Long W	Return position Lat N	Return position Long W	Distance traveled nautical miles	Distance traveled (km)	Days out	Velocity (knots)
1.	21913	44-39	124-11	46-43	124-06	123.4	228.5	22.0	.234
2.	21915	44-39	124-11	45-32	123-58	54.0	100.2	8.0	.282
3.	21722	44-39	124-25	46-53	124-08	134.0	248.0	13.0	.429
4.	20675	44-39	124-39	45-43	123-58	69.6	128.9	11.0	.264
5.	20865	44-39	126-03	46-03	123-56	122.2	226.3	51.0	.100
6.	20869	44-39	126-03	43-08	124-24	116.0	215.0	105.0	.046
7.	20764	44-39	126-59	47-11	124-14	191.6	354.8	61.0	.131
8.	20767	44-39	126-59	43-58	124-08	129.2	239.3	54.0	.100
9.	20770	44-39	126-59	44-18	124-06	125.3	232.1	51.0	.102
10.	20772	44-39	126-59	43-43	124-12	132.5	245.4	54.0	.102
11.	207[illegible]	44-39	127-27	46-28	124-04	178.7	331.0	70.0	.106
12.	2[illegible]	44-39	127-27	45-23	123-59	153.3	284.0	96.0	.067

This activity was adapted from "A Drift-Bottle Experiment Using R/V Yaquina data (Ocean Currents 1)" a Marine Science Education Tips bulletin published by the Oregon State University Sea Grant Marine Advisory Program.

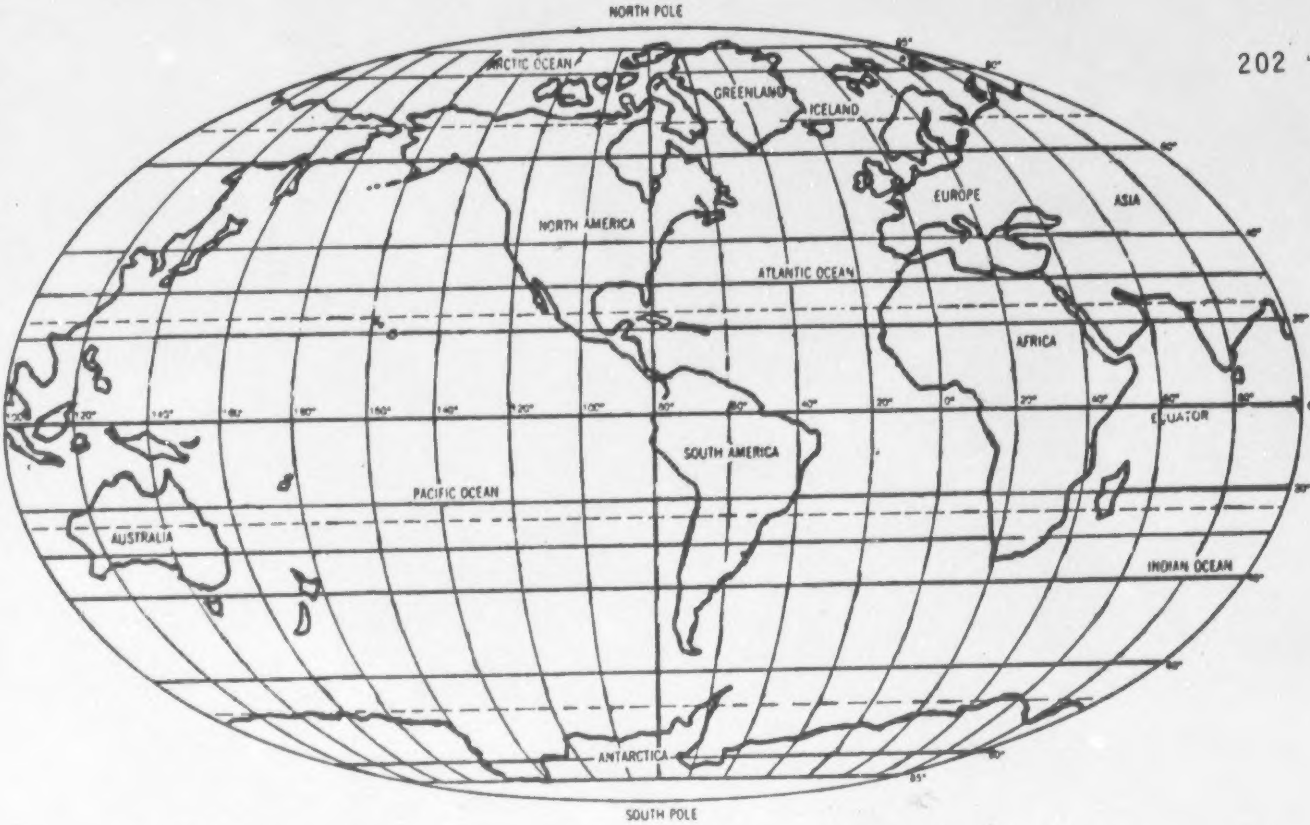
DRIFTING WITH THE R/V YAQUINA

Ocean currents are important to us in many ways. Currents influence climate, marine shipping, and the distribution of fish and other marine life. How are currents studied?

Scientists use drift bottles to measure ocean currents. The original drift bottles were simply glass bottles with a message placed inside and sealed with a cork or stopper. These glass bottles have been largely replaced by plastic disks or other devices with the message engraved on the surface. In this activity you will use actual drift-bottle data gathered on a cruise aboard the research vessel, R/V Yaquina off the Oregon coast in November, 1970. You will use this data to determine the speed and direction of surface currents.

Since you can't paint an "X" on the surface of the ocean, how can you locate the starting points for the drift bottles? We use the stars and sun to tell us our position in terms of latitude and longitude.

What are latitude and longitude? To measure the location of points on the earth's surface, imiginary lines have been drawn over the earth. The evenly spaced latitude lines tell us the distance


NORTH POLE
ARCTIC OCEAN
GREENLAND
ICELAND
EUROPE
ASIA
NORTH AMERICA
ATLANTIC OCEAN
AFRICA
EQUATOR
SOUTH AMERICA
PACIFIC OCEAN
AUSTRALIA
INDIAN OCEAN
ANTARCTICA
SOUTH POLE

north or south of the equator (the imaginary line around the earth located half way between the north and south poles). The longitude lines tell us the east and west distances. The east-west distances are referenced to the imaginary line that runs through Greenwich, England. Notice that the longitude lines get closer together as you leave the equator. The longitude lines converge (come together) at the poles.

Materials:

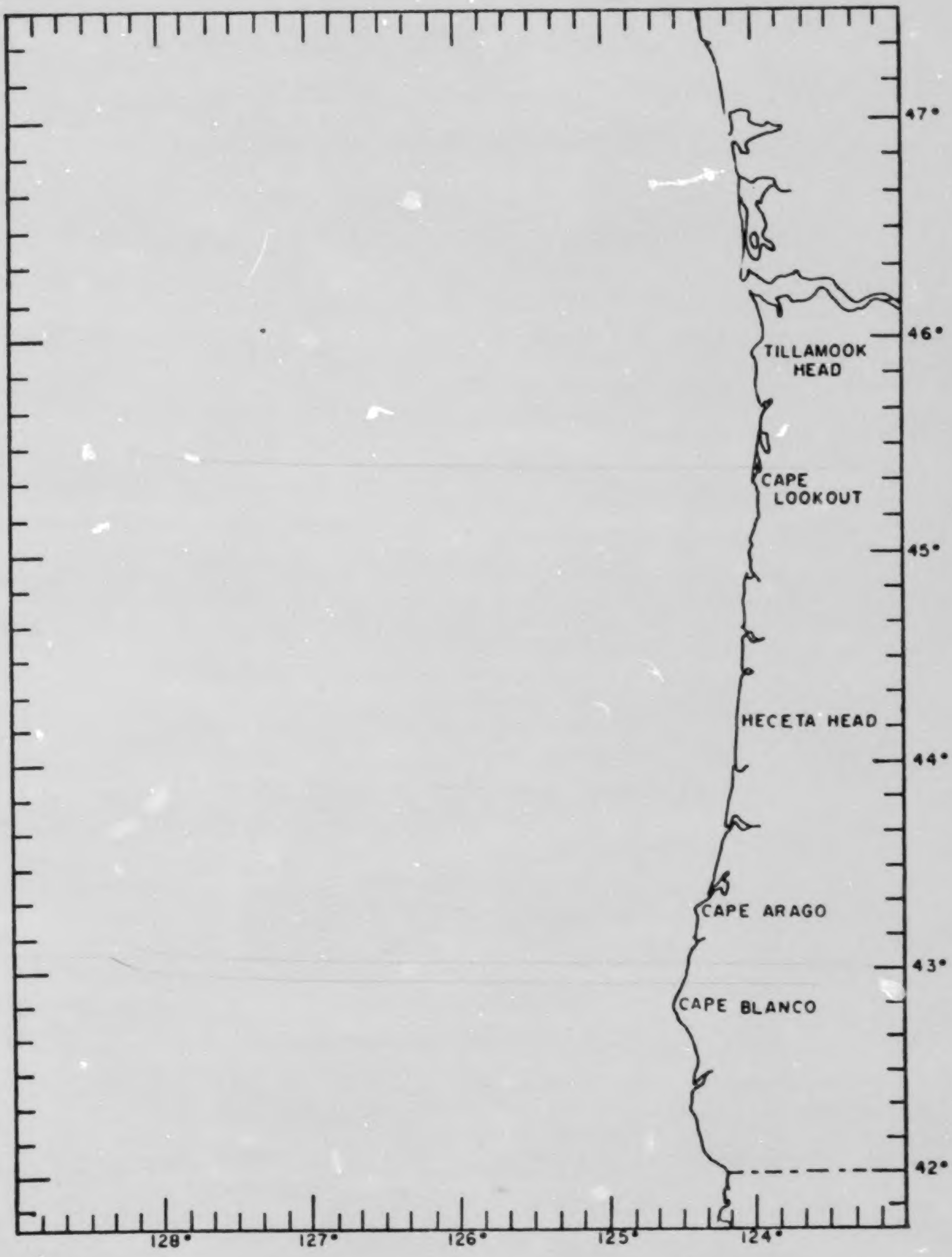
ruler

pencil

compass (optional)

Procedure:

1. Obtain a map of the Oregon coastline and a Drift Bottle Data Sheet.
2. Use the data sheet to plot the courses of the bottles the crew of the Yaquina released. To do this you will need to locate and mark two points for each bottle: the release point and the point


47°
46°
TILLAMOOK HEAD
CAPE LOOKOUT
45°
HECETA HEAD
44°
CAPE ARAGO
43°
CAPE BLANCO
42°
128°
127°
126°
125°
124°

of return. Each of these points can be located by using the latitude and longitude figures given in the data sheet.

3. No visual observation can be made of a drift bottle after it is released. As a result, it is impossible to draw the actual course the bottle follows. For this activity, we must assume that a bottle travels in a straight line from the point of release to the point of return.

4. From the information you have plotted on your map, determine the total distance each bottle traveled in degrees. To do this, first measure the length of the line from the point of release to the point of recovery. Next, lay your ruler along the vertical axis (latitude) of your map and note how many degrees of latitude correspond to your measured distance in centimeters. For example, if bottle number 13 traveled 3.5 centimeters you would lay the ruler against the latitude lines and see that 3.5 centimeters equals the distance from 43 degrees to 44 degrees or one degree of latitude. Latitude is measured in degrees. Each degree is subdivided into 60 minutes. Each minute may be further subdivided into 60 seconds. The latitude scale on your map is in degrees and minutes. If you have a compass, you can make these measurements more easily. Simply place one point of the compass on the point of release and the other on the point of recovery. Next move the compass over the latitude scale and read the number of degrees between the two points.

5. Calculate the number of nautical miles traveled by each bottle. You can do this by knowing that a minute of latitude equals one nautical mile. Add this data to your data chart.
6. Calculate the number of kilometers traveled by each bottle. One minute of latitude equals 1.852 kilometers. Add this data to your data chart.
7. Compute the speed of each drift bottle in nautical miles per hour (knots). Remember that there are 24 hours in a day! Add this to your data chart.

Results and Interpretation:

1. Which bottle traveled the greatest distance?
2. Which bottle had the slowest speed?
3. Which bottle made the greatest change in latitude? What was this change in degrees? In nautical miles?
4. One might expect that the further from the shore one dropped his drift bottle, the further north or south it would drift. Does the data from the R/V *Yaquina* support this generalization? Explain.
5. We have assumed that the drift bottles move in a straight line. Is this a reasonable assumption?
6. Electronic technology will now allow us to put a small radio transmitter in our drift bottles. How might this break-through help us in plotting the currents?
7. Does the distance from shore at which bottles are released have any effect on where they are *found*?

DRIFT BOTTLE DATA SHEET

Cruise Y7011B

November 19-21, 1970

Bottle No.	Release position Lat N	Release position Long W	Return position Lat N	Return position Long W	Distance traveled nautical miles	Distance traveled (km)	Days out	Velocity (knots)
1. 21913	44-39	124-11	46-43	124-06			22.0	
2. 21915	44-39	124-11	45-32	123-58			8.0	
3. 21722	44-39	124-25	46-53	124-08			13.0	
4. 20675	44-39	124-39	45-43	123-58			11.0	
5. 20865	44-39	126-03	46-03	123-56			51.0	
6. 20869	44-39	126-03	43-08	124-24			105.0	
7. 20764	44-39	126-59	47-11	124-14			61.0	
8. 20767	44-39	126-59	43-58	124-08			54.0	
9. 20770	44-39	126-59	44-18	124-06			51.0	
10. 20772	44-39	126-59	43-43	124-12			54.0	
11. 20781	44-39	127-27	46-28	124-04			70.0	
12. 20783	44-39	127-27	45-23	123-59			96.0	

8. Do all the currents off the Oregon coast run in the same direction? Add arrows to your map showing whether the currents move north or south.

9. The data used was gathered in November. Do you think data gathered at other times of the year would be the same? Explain.

TEACHER BACKGROUND - Drifting Further ....

"Drifting Further....." provides an opportunity to construct and utilize drift bottles to gather ocean current data. While this activity may present some logistics problems if you do not live on the coast, the problems are not insurmountable and the results, in terms of student interest and learning, are well worth the effort.

Duplicate the activity pages. One set is recommended per student. This activity can be done individually or in small groups. The glass bottles and caps can be brought by your students from home. Some drift studies average only a 10 percent return so you will want to make as large a number of drift bottles (perhaps 10 per student) as practical. Once you explain the purpose of your experiment, local boaters and fishermen are often more than willing to cooperate. If there are no local boaters because of your locale, get in contact with a marine extension agent in a coastal state who can arrange to have your bottles dropped. Extension addresses are included below. If you live near a body of water with ferry service such as the Puget Sound, you can arrange to drop your own drift bottles and chart currents in these inland waters. It is also possible to include more than one card in a bottle. In this case, you should use bottles with a slightly larger neck so that the cards may be removed without breaking the bottle. The finder then records the position of the find and returns the capped bottle to the water to continue its voyage. This adaptation will work best if you anticipate that your bottles will be found at sea. If you anticipate them washing ashore, one note is sufficient. You may elect to stamp the postcards or you may trust the finder to supply postage. If your school has a business reply permit with the post office you can mark the cards "Postage will be paid by recipient".

This permit enables you to pay for the cards returned. You can purchase a permit yourself, unfortunately the permits are about $30.00 or about 300 postcards! A large map with release and recovery points plotted adds to class interest. Plan to allow a few minutes for discussion of the general currents and what results might be expected. You might consider discussing questions 1 and 4 at this point.

KEY - answers

1. The sand was important to reduce the boyancy of the bottles and there-by reduce the effect of the wind on the bottles. The sand should be dry to prevent the note from absorbing the moisture and deteriorating.

2.& 3. Answers depend upon the results obtained.

4. This question provides a good springboard for discussion of marine pollution in general. What about the drift bottles? One might argue that the glass will only return to sand, but what about the plastic caps? Is the data gathered important enough to risk the loss of the non-returned caps? Will the materials actually end up on the land and actually become land pollution rather than marine pollution? The answers to these kinds of questions are important but the process of choosing between alternatives is more important and can be much more instructive and beneficial to your students.

5.& 6. Answers depend upon the results obtained.

KEY WORDS

ballast

currents

drift bottles

nutrients

upwelling

200

Extension marine agents who can provide information and assistance to you in your project.

Extension Marine Specialist
Cooperative Extension Service
Courthouse Box 552
Grays Harbor County
Montesano, Washington 98563

Extension Service
Sea Grant Marine Advisory Program
Oregon State University
Corvallis, Oregon 97331

Extension Marine Resources Specialist
Extension Wildlife and Sea Grant
554 Hutchison Hall
University of California
Davis, California 95616

This activity was adapted from "A Drift-Bottle Experiment You Can Do (Ocean Currents 2)" a Marine Science Education Tips bulletin published by the Oregon State University Sea Grant Advisory Program.

DRIFTING FURTHER........

Why should the crew of the R/V Yaquina have all the fun? You can make your own drift bottles and measure ocean currents using them. Map 1 shows the usual current patterns in the eastern Pacific Ocean. This map can help give you an idea of where your drift bottles will flow. The California current flows southward along the Pacific Coast past Mexico. The warm Davidson current which flows northward along the coast occurs only in late fall and winter when the wind frequently comes from a southerly direction. The shaded area shows a band of cold water which forms in the summertime. Summer northwesterly winds push the surface water away from the coast, allowing cold water from the ocean depths to move up and take its place. This upwelling of cold water carries nutrient rich ocean water up to levels where plants can use the nutrients. These areas of upwelling often support large commercial fisheries.

Materials:

glass bottles with screw-on caps (catsup, soft drink bottles or any others you can think of; clear glass is best)

dry sand

rubber stoppers size #1 or #2 (2 centimeters) or corks and paraffin

self-addressed postcards

letters to persons returning bottles

Procedure:

1. Prepare the data cards for your bottles. You can use U.S. post-cards which the finder may drop into a mail box within the U.S. without buying stamps or you can rely on the good will of the finder to provide the stamp. In any case, be sure each card is preaddressed to the school or class. A sample postcard is included on the next page.

PLEASE FILL IN THE INFORMATION REQUESTED AND RETURN THIS CARD BY MAIL. This drift bottle is being used as a part of a study of currents.

BREAK THIS BOTTLE

DATE FOUND______________ TIME FOUND_________________

WHERE FOUND, NAME OF BEACH OR PLACE ON SHORE, NEAR WHAT PROMINENT REFERENCE POINT:__________________________

____

____

____

BOTTLE NUMBER_____________

Stamp

Your Name
Your Address
Your City, State Zip Code

2. Make sure that each bottle is water tight. Roll the postcards and place one in each bottle.

3. Use dry sand to ballast each bottle so that only the top 1½ inches of the bottle remain above the water. You can test the ballasting in a sink or tank of water. This ballast will minimize the effect of the wind on the drift of the bottle.

4. Seal each bottle with a rubber stopper and, if available, the screw-on cap (preferably plastic). You may use corks instead of rubber stoppers and caps but they must be sealed with wax. Even so, air bubbles in the wax will eventually break and the corks may be eaten by marine organisms causing the bottles to sink.

5. When you have sealed all of the drift bottles, they are ready for release in the ocean. You can talk to local fishermen or boaters or arrange with your Marine Extension agent to have your bottles dropped at sea. Be sure that the person who drops the bottles for you records each location of release by recording the latitude and longitude. If at all possible arrange that bottles be released at different distances from shore - for example: 3,5,10. and 15 nautical miles. If you have bottles released from different points, indicate on each postcard the distance from shore that the bottle was dropped.

6. Recovering drift bottles. Many people beach comb and are likely to find a drift bottle. Maintaining public interest in drift studies is most important. To perform an educational service and to maintain public interest, send a letter and a map to each person who returns a drift-bottle card. The letter should explain your drift-bottle project and its objectives. The map should show ocean current patterns off the U.S. west coast so the finder will understand why he or she found the bottle. Sample maps and letters are included. Remember: the success of your drift bottle project depends upon keeping the public informed of what you are trying to do.

Results and Interpretation:

1. Why was the dry sand important for accurate results?

2. On a nautical chart plot the release and return points of your drift-bottles just as you plotted the paths of the bottles from the R/V Yaquina.

3. Make a table which gives the bottle number, the release position, the return position, and the days out. Use this table to determine the distance traveled/in nautical miles and the speed in knots.
4. Do drift bottles contribute to the pollution of the sea? One class discussed this; their answer was to add to the message they put in their bottles. They requested that the finder properly recycle the bottle or bottle parts.
5. How do your drift bottle results compare with the currents shown on the map on the next page? If the two are different, what might account for the differences noted?
6. Does the distance from the shore at which the bottles were released have any effect on where they were found? What is the observed effect?
7. For some years radioactive wastes were placed in concrete barrels and dumped into the ocean just north of San Francisco. Recently, divers have discovered that many of these barrels have split open. If you were to look for the escaped radioactive wastes, where would you look in the winter? in the summer?

   How could drift bottle information help you in your investigation?

Marine Science Center

Marine Science Center
North Kitsap School District
215 3rd Avenue South
Poulsbo, Washington 98370
Phone: (206) 779-5549

Dear Sir:

Thank you for returning the drift card no ____________________ which you found at ____ on ____________________. The drift bottle was released on ______________________ at the following location: ____________ ____ It traveled ______________ miles in less than ____________ days at a rate of ____________________ knots. We conduct this program to learn about the currents off the Pacific coast. The bottles are released offshore and are weighted with sand to submerge them enough to lessen the influence of wind on their movement.

The attached map shows the usual patterns of ocean currents in the eastern Pacific Ocean. The California current, a major ocean circulation off the Pacific coast, flows southward along the Pacific Coast past Mexico to become the North Equatorial Current. The warm Davidson current, shown flowing northward along the coast, occurs only in late fall and winter when southerly winds are common.

The map also shows a band of cold water along the Pacific Coast. This cold water forms in the summertime when north-westerly winds push the surface water seaward away from the coast. This movement allows cold water from the ocean depths to move up to take its place. This upwelling helps account for the good fishing off of the coast. The currents also play a major role in determining the climate, including fog, off the coast.

This is the (1st, 2nd, etc) release of drift bottles by the (your name). Bottles from these releases have been returned from as far away as ______________________________.

Thank you very much for your cooperation in this project.

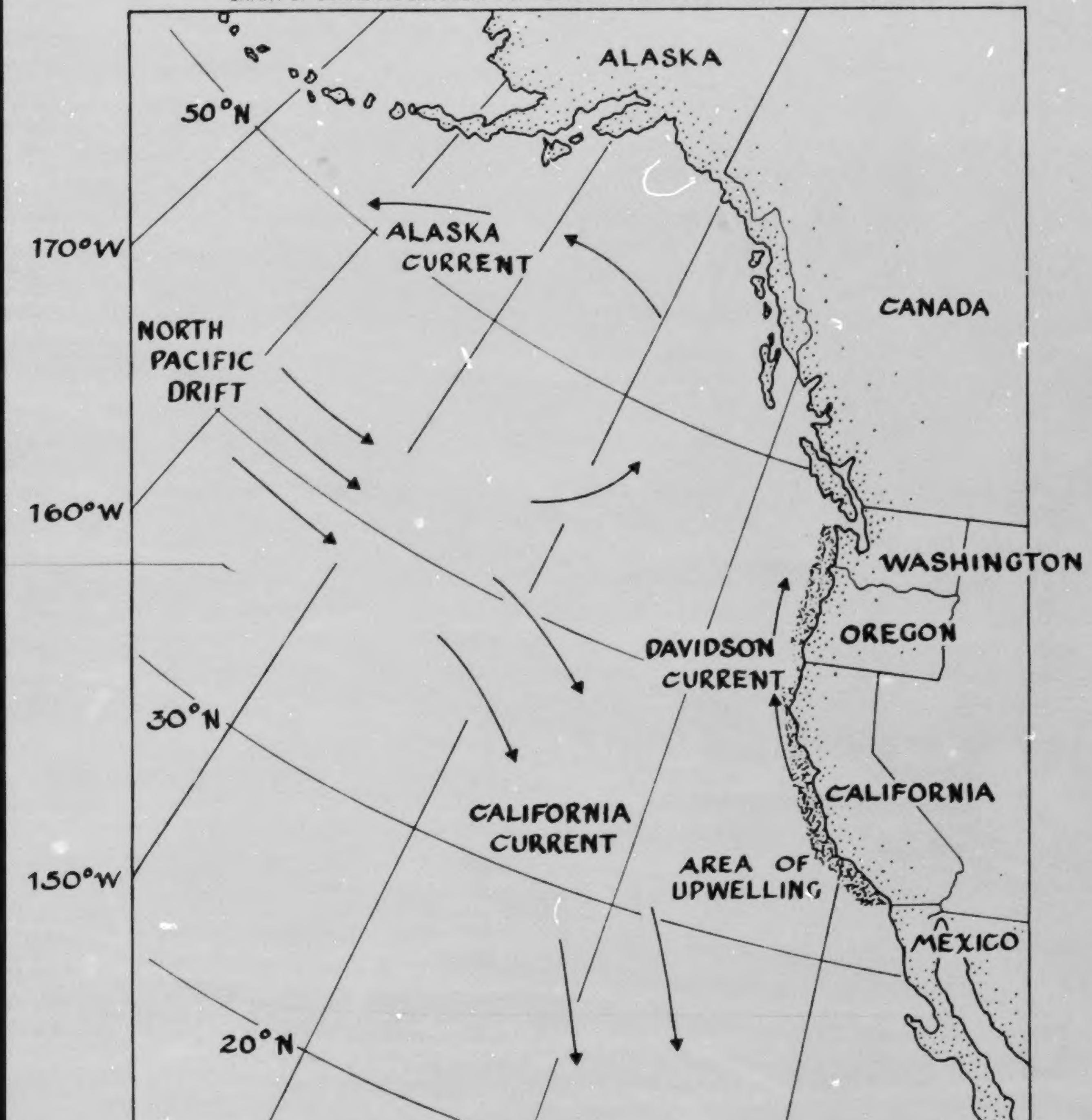
Sincerely,

I.M. Allwet
Director

SEA ANEMONE
(Anthopleura sp.)

Although it may look like a flower this creature is an animal with a large stomach and stinging cells on its tentacles that poison small animals which are then eaten. The anemone is common throughout Puget Sound

CHART OF CURRENTS ENCLOSED WITH LETTER TO PERSONS RETURNING DRIFT BOTTLES


ALASKA
50°N
ALASKA CURRENT
170°W
CANADA
NORTH PACIFIC DRIFT
160°W
WASHINGTON
OREGON
DAVIDSON CURRENT
30°N
CALIFORNIA
CALIFORNIA CURRENT
AREA OF UPWELLING
150°W
MEXICO
20°N
140°
130°
120°W

MAP 1

TEACHER BACKGROUND - The Circulation of the Oceans

Knowledge of the existance of ocean currents has been with us for some time. Yankee sailing skippers used the Gulf Stream current to their advantage in trade with England before the revolutionary war. Even so the circulation of the oceans is far from completely understood. Active research is being conducted to determine the immediate causes of the currents. Currents influence our climate as well as our shipping and commerce. The article The "Circulation of the Oceans," gives the reader a picture of the state of current research on currents and summarizes our knowledge to date.

Duplicate the puzzlegram pages. One set is recommended per student. This activity may be performed individually or in small groups. Each approach has its advantages and disadvantages. Select the technique that best suits your particular needs. The puzzlegram is a modification of a reading game designed to teach vocabulary skills. This puzzlegram teaches vocabulary skills to a degree but the emphasis is on concepts. Completing the clues by filling in the blanks completes statements which are important concepts from the article. While the directions on the student sheets are designed to be self-explanatory, a few words about the format may be in order. Explain that when all of the blanks are correctly completed a term dealing with ocean circulation will appear. Each blank receives one letter. Plan to allow a few minutes for discussion of the concepts elucidated by the article and reviewed by the puzzlegram. Provide the correct answers during the course of your discussion.

THE CIRCULATION OF THE OCEANS

by WALTER MUNK

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SCIENTIFIC
AMERICAN
SEPTEMBER 1955

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The Circulation of the Oceans

Driven by winds, the ocean waters flow in complex patterns whose broad outlines are beginning to be understood. Curiously, tiny ripples rather than large waves take up most of the winds' energy

by Walter Munk

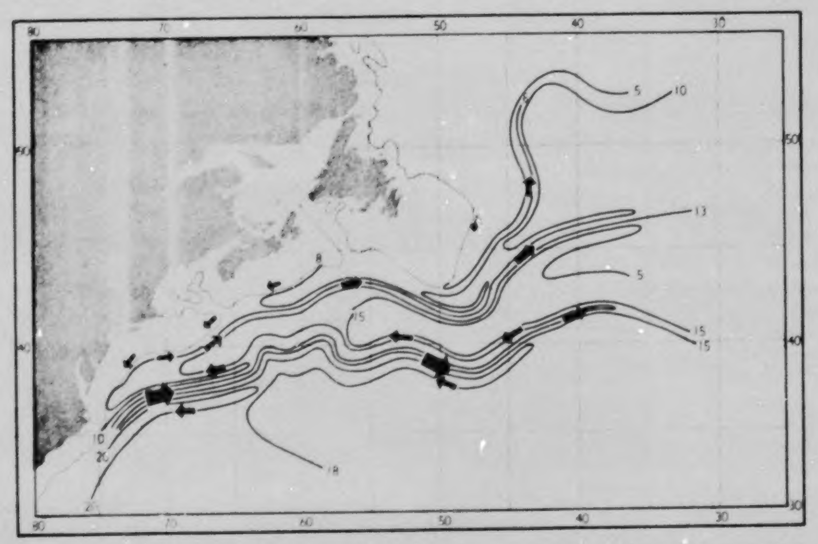
Everybody knows the difference between climate and day-to-day weather. It is less known that a similar distinction applies also to the currents of the oceans. Until recently we were aware only of the broad, average features of the ocean movements—the "climatic" circulation. But modern studies have disclosed a fine structure which is superposed on this climate and which shifts from day to day in an unbelievably mercurial manner. If 10 vessels strategically placed in the Gulf Stream were to measure the currents and make a "weather map" of the Stream next Tuesday, the map would differ from the one for Friday. Not long ago we watched a freighter carefully holding a course which according to the climatic chart should have speeded it on its way to Europe by taking advantage of the Gulf Stream. Actually the ship was bucking a two-knot countercurrent; the Gulf Stream was 100 miles off its usual path!

The vagaries of the ocean currents were practically unknown until the last world war, when new techniques and more detailed mapping disclosed that currents in the Atlantic were not as steady or predictable as the earlier climatic maps had suggested. The upshot is that oceanographers have now become interested in two kinds of maps: the climatic map, which shows the average currents over a large area for a year, and the "synoptic" map, which is like a daily or weekly weather report, showing how the currents change from one week to the next. The currents look quite different in the two charts. In the synoptic picture they are narrow, winding and fast; in the climatic picture they are smooth, broad and slow.

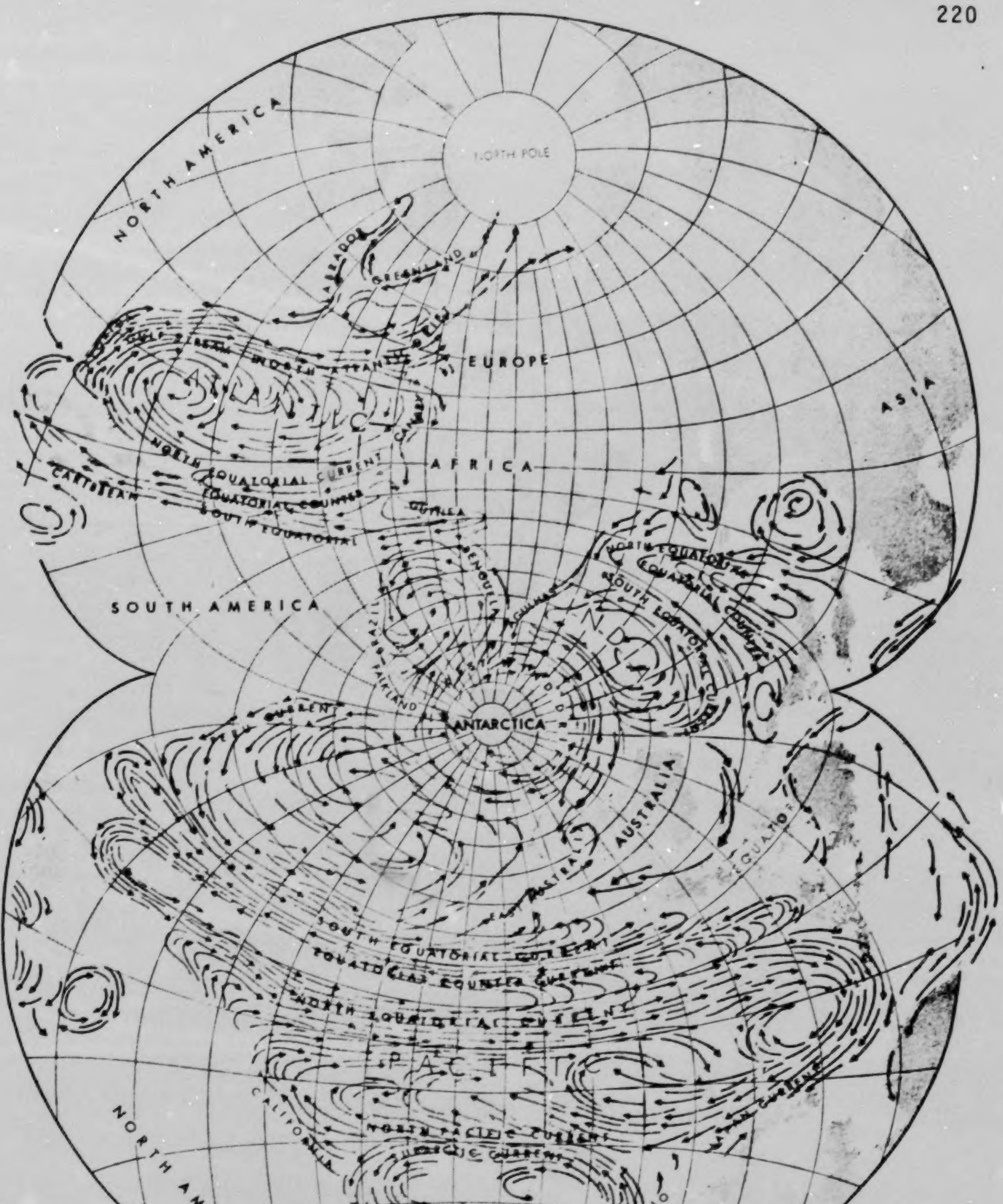
Both charts have their uses. If you want to study a long-term phenomenon such as the transport of sediments by currents off the coast of a continent, the climatic chart will be the one you need. On the other hand, if you are piloting a ship or submarine, you will find the synoptic chart much more useful.

Oceanographers have mapped the general circulation of all the world's oceans, relying mainly on a method which is like that for determining air currents in the atmosphere; that is, the currents are deduced from pressure fields in the sea, which in turn are indicated by measurements of water salinity and temperature [see "The Anatomy of the Atlantic," by Henry Stommel; SCIENTIFIC AMERICAN, January, 1955]. The map on facing page summarizes what we know about the climatic circulation of the oceans' surface (the top 1,000 feet).

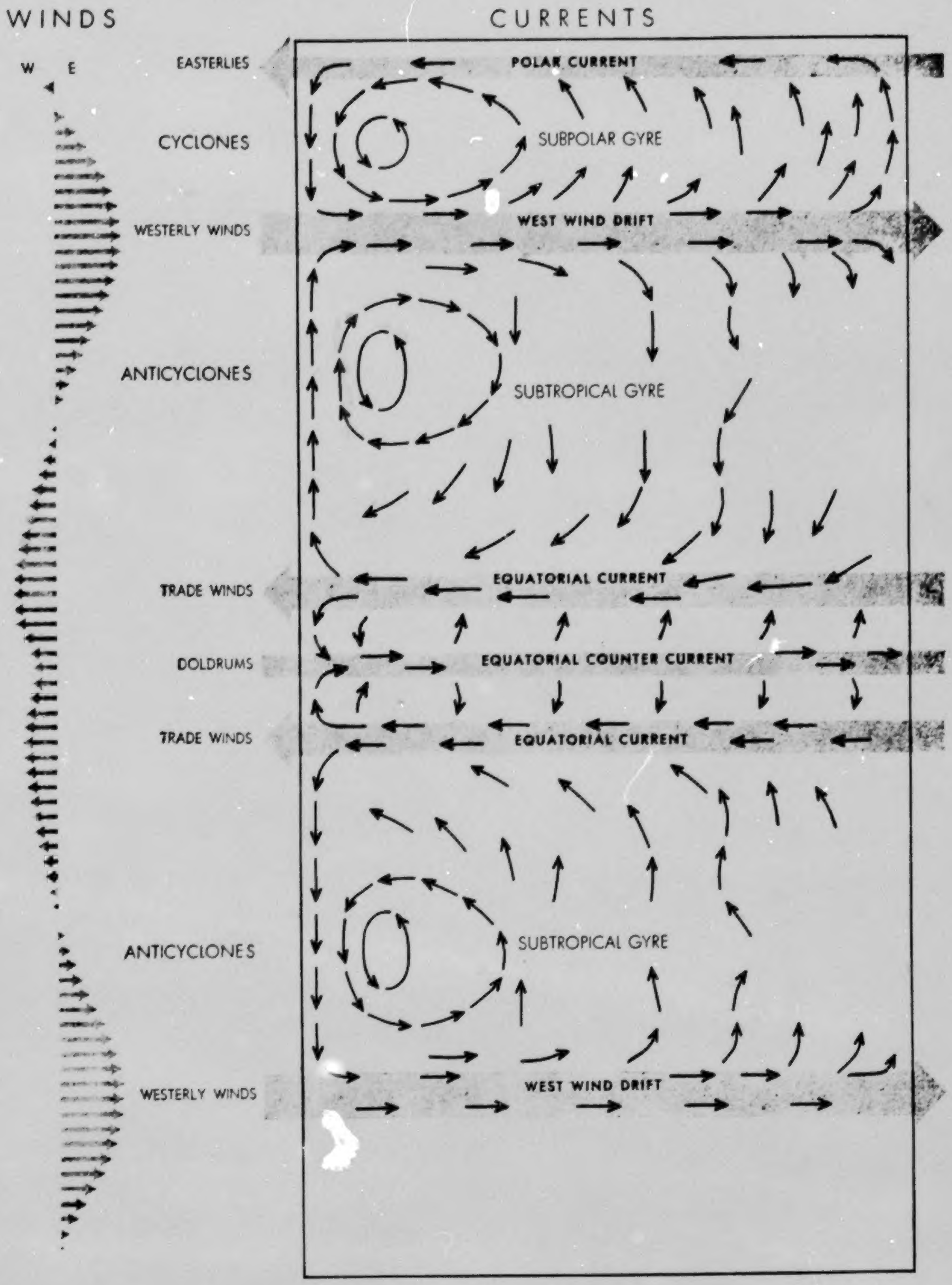
Is there any system to this complex circulation pattern—any clue to how it may be produced? I think there is, and the chart on page 4 is an attempt to analyze the chief elements of the picture. Suppose we plot the currents that should appear in an idealized rectangular ocean responding to the known winds that blow over the world at the various latitudes. (To simplify things we take into account only the east-west components of the wind system, disregarding "details" such as the winds blowing around the Bermuda high.) The circulation in this schematic ocean then divides into several gyres (rings) corresponding to the wind belts—a counterclockwise gyre in the subpolar region, a clockwise circulation in the subtropical belt above the equator, a narrow gyre on each side of the equator and a counterclockwise gyre in the subtropical region below the equator. In each gyre there is a strong, persistent current on the western side



GULF STREAM, examined in detail, exhibits the narrow, fast-flowing filaments typical of all ocean currents. The solid lines mark regions of equal temperature, measured in degrees centigrade. The dotted line indicates the point at which the bottom is deeper than 100 fathoms.


NORTH POLE
NORTH AMERICA
LABRADOR
GREENLAND
GULF STREAM
NORTH ATLANTIC
EUROPE
ATLANTIC
CANARY
ASIA
NORTH EQUATORIAL CURRENT
AFRICA
CARIBBEAN
EQUATORIAL COUNTER
SOUTH EQUATORIAL
GUINEA
BENGUELA
SOUTH AMERICA
BRAZIL
FALKLAND
ANTARCTICA
INDIAN
NORTH EQUATORIAL
EQUATORIAL COUNTER
SOUTH EQUATORIAL
AUSTRALIA
EAST AUSTRALIA
EQUATOR
SOUTH EQUATORIAL CURRENT
EQUATORIAL COUNTER CURRENT
NORTH EQUATORIAL CURRENT
PACIFIC
CALIFORNIA
NORTH PACIFIC CURRENT
ALASKA CURRENT
OYASHIO
NORTH AMERICA
ASIA

CLIMATIC CIRCULATION in the ocean basins is illustrated on this unusual projection. Colored arrows show the present picture of the average currents. Equatorial countercurrent, which is present in all the oceans, lies five degrees north of the geographic equator.


WINDS
CURRENTS
W
E
EASTERLIES
CYCLONES
WESTERLY WINDS
ANTICYCLONES
TRADE WINDS
DOLDRUMS
TRADE WINDS
ANTICYCLONES
WESTERLY WINDS
POLAR CURRENT
SUBPOLAR GYRE
WEST WIND DRIFT
SUBTROPICAL GYRE
EQUATORIAL CURRENT
EQUATORIAL COUNTER CURRENT
EQUATORIAL CURRENT
SUBTROPICAL GYRE
WEST WIND DRIFT

IDEALIZED OCEAN, rectangular in shape and subject only to the horizontal wind forces shown by the broad gray arrows, would have the circulation patterns traced by the black arrows. Approximate relative velocities of surface winds are indicated at left.

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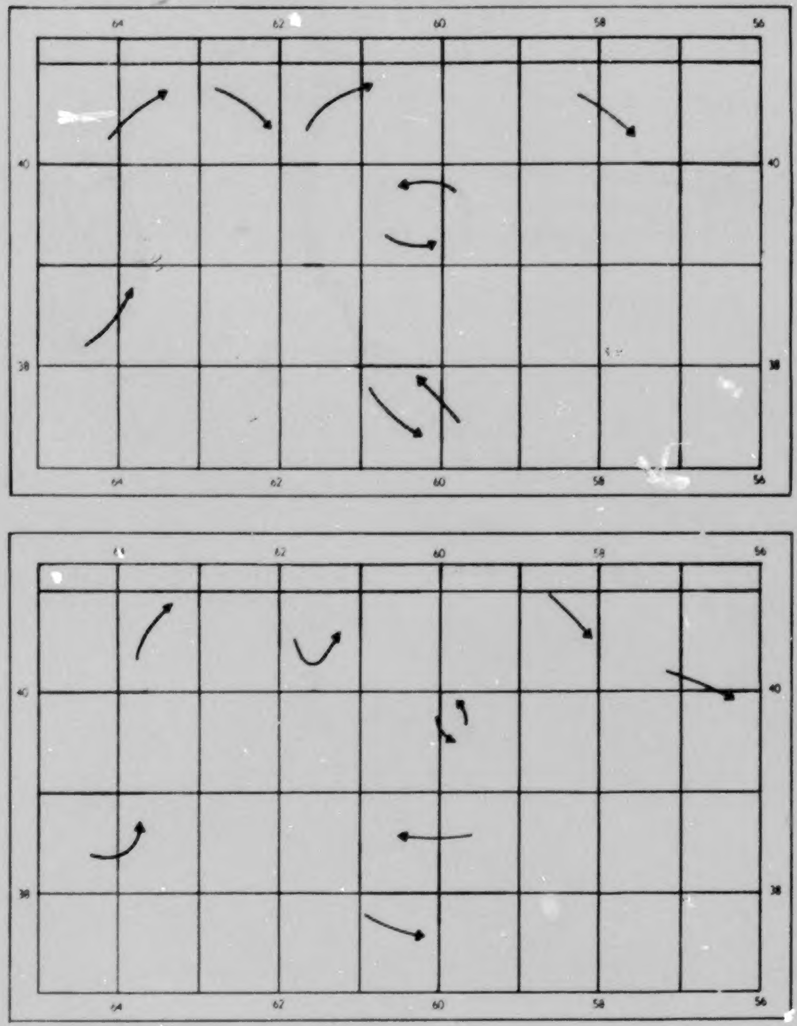
(due, as we shall see, to the rotation of the earth) and a compensating drift in the central and eastern portion.

With some imagination we can recognize this pattern in the three major ocean basins of the earth. The strong western current appears as the Gulf Stream in the North Atlantic, the Kuroshio in the North Pacific, the Brazil current in the South Atlantic, the Agulhas in the Indian Ocean, and possibly the East Australia current in the South Pacific. The current driven by the strong west winds in the "roaring forties" of the Southern Hemisphere flows not in a gyre but right around the globe, because no continent stands in its path; this is the mighty Antarctic circumpolar current.

The ocean-current gyres in our picture correspond closely not only to the wind systems but also to chemical and biological properties of the ocean regions. Each subtropical gyre, for example, encloses a sea which is relatively warm, salty, poor in phosphates, low in biological activity and blue in color (blue is the desert color of the sea). At the boundaries of the gyre these conditions change sharply. And the center of each gyre, near the western shore, is an unusually stable environment. The best known such region is the Sargasso Sea in the Atlantic, named after its sargassum, or gulfweed. Very possibly the six other similar regions in the world—the centers of the subtropical gyres in other oceans—will be found to have like populations of floating sea life with narrow environmental tolerances; that remains to be explored.



GULF STREAM EDDY begins with the formation of a 250-mile loop in the current (*top*). Four days later, loop has been pinched off (*bottom*). Gray indicates cold subarctic water.

The precise mechanism whereby the winds produce the circulation gyres is complex and not clear. First of all, the action of wind upon water is itself a complicated matter. Wind can move water simply by frictional force as it slides over the surface, even when the surface is smooth. It must also accelerate the motion of water when it picks up spray and throws it down again, particularly during hurricanes, when so much water is pulled up into the air that the "boundary" between the sea and the air is lost. Another important means by which wind drives ocean water is its pressure on the waves as it sweeps over rough water—just as wind blowing over a field bends the blades of grass because pressure is higher on the windward sides than on the lee sides. It turns out that the important elements in the response of water to wind are not the large waves that rock boats and make people seasick, but the tiny bumps, the ripples. If we could cover the North Atlantic with oil and smooth these ripples, the Gulf Stream would lose an appreciable part of its strength. The importance of these tiny waves is surprising. Would any honest seafaring man care to admit that the tiny ripples, to which he paid so little attention, may have been partly responsible for setting him off his course?

How do the driving winds produce the great circulations (gyres) that we see in the oceans? During the last 10 years a theory has been developed. We start with a situation where no land barrier stands in the way of the wind-driven water. The currents will then flow in a great circle around the earth, as they do around the Antarctic Continent [*see page 6*]. Things get more complicated when we introduce land masses. Suppose we erect barriers and make an enclosed sea. Now if winds blow only from the west and have equal force at all latitudes in this sea, there can be no rotary circulation or currents; just as a paddle wheel subject to equal force from the same direction on its opposite blades will not turn. The wind will simply pile up water on the eastern side of the sea. But if the wind is stronger at some latitudes than at others, the stronger will overpower the weaker and the water will begin to circulate. The circulation will be even stronger, of course, if the winds at different latitudes blow in opposite directions. To this effect we must now add the effect of the earth's rotation. The turning of the earth toward the east exerts a torque on the ocean circulation, with the result that the center is displaced toward the west and the currents are intensified on the western side [*see lower drawing on page 7*].

In general the great wind-driven currents in the world's oceans do fit this model and the theory derived from it. The boundaries of the major currents are where they should be in relation to wind systems, and the strong western currents also appear where they should. Moreover, the theory has received some support from a laboratory model simulating ocean circulations. William von Arx, of the Woods Hole Oceanographic Institution, performed these experiments with a rotating basin shaped like a roulette wheel—essentially a hemisphere turned inside out. His "oceans" consist of a thin film of water clinging in an equilibrium distribution over the surface of the whirling basin, and winds are blown on the water from nozzles on vacuum cleaners. Von Arx projects the Northern Hemisphere into this basin, with the North Pole at the low point in the center. Potassium permanganate crystals are placed in the center, and when ink is introduced into the water, it reacts with the chemical to show the flow patterns in different colors. Von Arx's model faithfully reproduces the gyres of the North Atlantic and the North Pacific, including the intense western currents. The model is especially interesting because the topography and winds can be varied to show possible circulations of the oceans in the past, when conditions were different; for instance, one can investigate how the Gulf Stream might have behaved at a time when there was a separation between North and South America in the place of the present Isthmus of Panama.

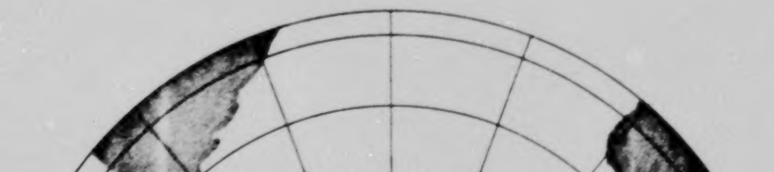
It must not be supposed that the theory about how the ocean circulations are produced is fully confirmed by these observations and experiments. There are many inconsistencies; in particular, some of the circulation in the oceans of the Southern Hemisphere refuses to fit into the pattern pictured by the theory.

This is where we stand, then, on the climatic circulation. The era of measurement of the synoptic circulation, or day-to-day ocean weather, began with the recent invention of certain new techniques and instruments, notably (1) the radio location method called "loran," (2) the instrument for rapidly measuring temperatures at various depths which is called the "bathythermograph," and (3) an instrument, invented by von Arx and named the "geomagnetic electrokinetograph," which determines the motion of ocean water by measuring the electric potentials induced in it because of its movement through the earth's magnetic field.

Resurveying the Gulf Stream with these techniques, Columbus O'Donnell Iselin and his collaborators at Woods Hole discovered that the Stream was narrower and much faster than had been thought. As their instruments and techniques improved, the current became even narrower and faster. They also found that the position and direction of the current varied from one cruise to the next. A five-ship expedition called Operation Cabot was organized by the U. S. Navy Hydrographic Office in 1950 to study the Gulf Stream more closely. This cruise detected a most important and dramatic phenomenon: the Gulf Stream meandered off the usual course to form a loop 250 miles long! Within two days the loop broke off and separated as an independent eddy [*see charts on page* 5]. The eddy then gradually weakened.

It is estimated that this single eddy injected some 10 million million tons of subarctic water from the North Atlantic into the subtropical Atlantic. Obviously such an immense transport of water, with its content of living organisms, must be of considerable importance to the biology of the sea. Possibly similar eddies of water from the south break off toward the north, injecting subtropical water into the colder part of the ocean.

Frederick Fuglister of Woods Hole, an artist who has been in oceanographic work since the war, later discovered some other unsuspected characteristics of the Gulf Stream. Plotting currents by means of temperature gradients measured with the bathythermograph, he found a pattern which suggested that the Gulf Stream consists of a number of long, narrow, separate ribbons, or filaments. They are not continuous over thousands of miles; as a rule one will peter out and another will start somewhere else. In other words, it appears that the concept of a single, continuous Gulf Stream all the way from Florida to Europe must be abandoned. Rather one must visualize the Stream as composed of high-speed filaments of current separated by countercurrents [*see chart on page* 2]. L. V. Worthington of Woods Hole, using all the modern tools, has substantially confirmed this picture with detailed cross-section studies. In one 30-mile cross section he found three separate major filaments, each flowing at better than three miles per hour. Gunther Wertheim, also of Woods Hole, further demonstrated the



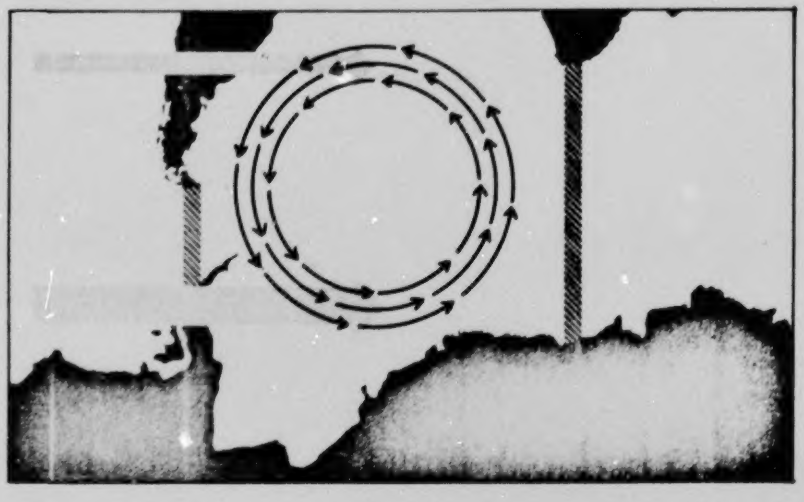
ANTARCTIC CIRCULATION is relatively simple because no land barriers prevent the waters from responding to the prevailing west winds. West-to-east current rings continent.

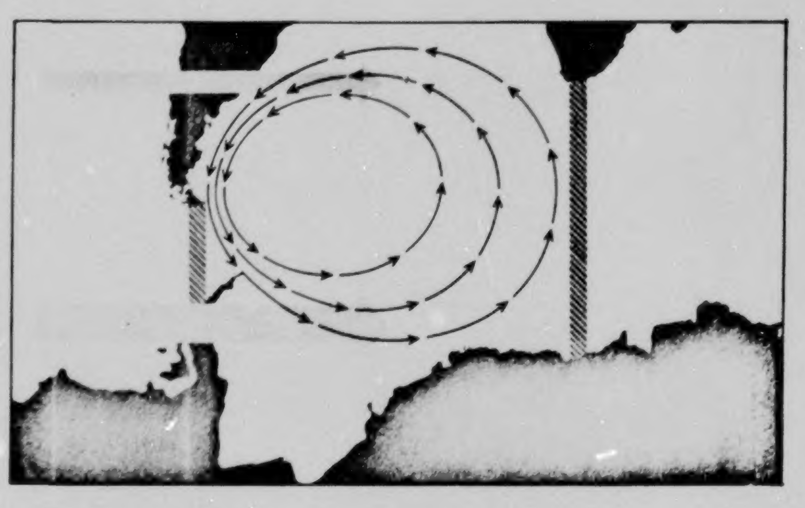
complexity and variability of the Gulf Stream by discovering that the transport of water by the Florida current section of the Stream doubled from one month to the next! He computed the movement of water from measurements of electric potential between Havana and Key West, made by attaching electrodes to the Western Union telegraph cable between those points.

Fuglister has satisfied himself that the Japanese current also can be interpreted as consisting of filaments; in fact almost everywhere we look the ocean weather seems extremely fickle. Henry Stommel, monitoring radio drift buoys near Bermuda, found the currents highly changeable; every sudden waxing or waning of the winds set up rotary currents.

My interpretation of the new look with regard to the ocean weather is something like this. The motion of water in the open sea is highly irregular and variable. If we release a drift buoy, we can expect the current to carry it something like half a mile in an hour, but the velocity and the direction will be quite different from one day to the next. This unsteady motion—the "noise" of the ocean circulation—represents in some way the response of the sea to the multiplicity of shocks it receives from the wind blowing on its surface. The response is not simple, and the underlying laws have not yet been recognized. The transient ocean weather, unlike the slow climatic circulation, apparently has no blow-by-blow counterpart in the circulation of the atmosphere.

The fine structure of the ocean currents can be tied in with the climatic circulation only in a general way. It evidently results from the fact that the broad circulation cannot dissipate all the energy received by the ocean from the wind, but just why the fine structure takes the forms it does is a problem awaiting further exploration.





IMAGINARY SMALL OCEAN, made by enclosing part of the Antarctic waters with walls extending to South America and Africa, would circulate as shown at top if west winds in the south were stronger than those farther north. The effect of the earth's rotation would be to shift circulation pattern westward, as at bottom, compressing currents at the west wall.

The Author

WALTER H. MUNK is professor of geophysics at the Scripps Institution of Oceanography in La Jolla, Calif. He was born in Austria—"a country which boasts of several oceanographers but of no oceans." He took an M.S. in geophysics at the California Institute of Technology and, in 1947, a Ph.D. in oceanography at the Scripps Institution. He writes: "Ever since I first took up science I have resented the need of having to specialize, of having to decide whether to push a pencil, to play with gadgets or to do field work. I have ended up in a field where I can do a bit of each."

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KEY

1 OCEANOGRAPHERS
2 PRESSURE
3 RECTANGULAR
4 FOR
5 WESTERLYWINDS
6 DESERT
7 RIPPLES
8 CIRCLE
9 LATITUDES
10 MODEL
11 CARRY
12 TEMPERATURE
13 RIBBONS
14 IRREGULAR
15 MILE
16 ROTATION
17 EXPLORATION

KEY WORDS

bathythermograph

climatic current maps

circulation

corresponds

drift bouy

gradients

gyre

latitudes

model

pressure

puzzlegram

ripples

synoptic current maps

temperature

variable

velocity

westerly winds

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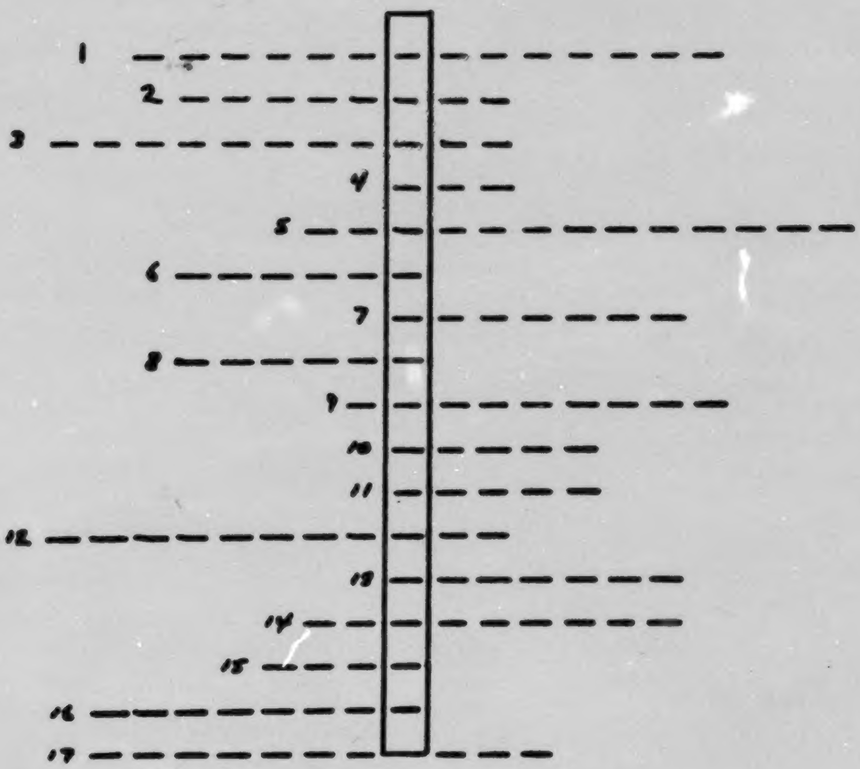
THE CIRCULATION OF THE OCEANS

Fill in the blank space with the correct word in each of the sentences beneath the puzzlegram. The number of the sentence corresponds to a number in the puzzlegram. The correct answer will have the number of letters indicated by the number of blanks in the puzzlegram. When you have answered all of the sentences and filled in the blanks of the puzzlegram, a term dealing with ocean circulation will appear.



1. ______________have now become interested in two kinds of current maps: climatic maps which show average currents over a large area for a year and synoptic maps which are like a daily or weekly weather report.

2. Currents are deduced from ______________fields in the sea.

3. The author, Walter Munk, uses a model to help explain ocean circulation patterns. In his model he uses an idealized ______________ocean and known winds.

4. Gyre is another word ______________ring.

5. From the chart "Idealized Ocean", the idealized ocean would have greatest velocity winds in the area labelled ______________(2 words).

6. Each subtropical gyre encloses a sea which is blue in color. Blue is the ______________color of the sea.

7. It appears that an important element in the response of water to wind is not the large waves that rock boats and make people seasick, but the tiny bumps, the ______________.

8. If there were no continents, the currents would flow in a great __________ around the earth.

9. If wind is stronger at some ______________ than at others, the stronger will overpower the weaker and the water will begin to circulate.

10. William Von Arx of the Woods Hole Oceanographic Institution constructed a ______________ that simulated ocean currents and seems to support the theories of the author of this article.

11. Ocean currents can be of considerable importance to the biology of the sea because they can ______________ a large number of living organisms.

12. Currents can be plotted by means of ______________ gradients measured with the bathythermograph.

13. Research suggests that the Gulf Stream rather than being a wide river of moving water may be made up of narrow, separate ______________.

14. The motion of water in the open sea is highly ______________ and variable.

15. A drift buoy released in the ocean, could be expected to be carried something like 1/2 a ______________ in one hour.

16. The diagram labeled "Imaginary Small Ocean" shows that the earth's ______________ causes the circular pattern of water flow to be shifted into an egg shaped pattern.

17. Why the fine structure of the ocean circulates the way it does is a problem awaiting further ______________.

PHYSICAL FACTORS:
PRESSURE

TEACHER BACKGROUND - The Pressure's On

"The Pressure's On" looks at a physical factor that greatly affects marine organisms living in the ocean depths. Structure and function in deep ocean fish is influenced by pressure. As recently as the middle of the last century scientists thought that no life would be found in the great depths of the ocean. They believed that high water pressures and lack of light would create an environment that could not support life. We now know that there is quite an assortment of marine animals that can live deep beneath the surface. This activity explores some of the ways deep sea animals deal with pressure.

Duplicate the activity pages. One set is recommended per student. This activity is best accomplished on an individual basis with group or class discussion as a follow-up.. A period for discussion and review of the correct answers should be planned for the end of the exercise.

The concepts of pressure and surface area will likely be unfamiliar to many of your students. The English system of units has been used in parts of this activity since it is likely to still be more familiar to your students. Metric equivalents are included where helpful.

KEY

1. The force on a fish with one square foot of surface area at a depth of feet would be:

$$\frac{\text{64.6 pounds}}{\text{cubic foot}} \times \text{36,200 feet} = \text{2,338,520 pounds per square foot!}$$

2. The force on each square inch of a fish at 36,000 feet would be

$$\frac{\text{2,338,520 pounds per square foot}}{\text{144 square inches per square foot}} = \text{16,239 pounds per square inch.}$$

3. Mr. Shood B. Flat is subjected to a total force of 37,843.2 pounds.

4. The pressure exerted by the water on one square foot of surface area was equal to:

$$\frac{64.6 \text{ pounds}}{\text{cubic foot}} \times 3{,}000 \text{ feet} = 193{,}800 \text{ pounds per square foot}$$

5. The surface area of the circular window was:

$$A = \pi r^2 = 3.14 \times \left(\frac{1.5 \text{ feet diameter}}{2}\right)^2 = 1.77 \text{ square feet.}$$

6. To find the force per bolt we first need to calculate the total force on the window:

$$\frac{64.6 \text{ pounds}}{\text{cubic foot}} \times 1.77 \text{ square feet} \times 3{,}000 \text{ feet} = 343{,}026 \text{ pounds.}$$

The force per bolt would equal:

$$\frac{343{,}026 \text{ pounds}}{10 \text{ bolts}} = 34{,}302.6 \text{ pounds.}$$

The purpose behind these mathematical manipulations is to impress the student with the tremendous forces involved with ocean depths.

7. There are several kinds of experiments that your students may suggest to test the hypothesis that angler fish move up into the lighted ocean zones. Some are practical, some are not. Some possible suggestions: Mark fish (either with dye or radioactive tracers) and follow their movements by radio or visually; put the fish in a pressurized aquarium and watch its behavior; fish for gulpers in the lighted ocean zones, etc. Originality here should be rewarded with a kind word and not with criticism about impracticality.

8. Answers will vary.

9. The observation suggests that gulpers may use their tails to hold their prey, or perhaps even to catch it.

10. Bioluminescence is an interesting phenomena. It is suggested that it may help in the location of mates, in species recognition, or perhaps in communication. Other theories are also possible.

11. Since the outside pressure on the cells decreases as the fish swims upward, the fish needs to compensate by decreasing the inter-cullular pressure at the same rate. Fish can withstand small changes in depth with no compensation. Large changes in depth, however, require some adjustments.

KEY WORDS

adaptations
air bladder
angler
atmosphere
bathysphere
bioluminescence
cataract
cubic foot
decapitated
evolutionary forces
force
hurtled
hypothesis (-sized)
lateral line system
lure
pressure
quartz
square foot
square inch
surface area
trajectory
trawl
volume
winch

THE PRESSURE'S ON

The ocean is deep. If we shaved off all of the continents and filled the trenches in the oceans with the earth from the continents, the entire globe would be covered with water about 2 miles in depth. The average ocean depth is 12,566 feet (about 3800 meters). The greatest ocean depth is 36,200 feet (over 11,000 meters) over six miles deep! What effect does this great depth of water have on things living in the ocean? The answer depends upon where in the ocean the living thing lives. A fish or a plant near the surface feels little effect from the great depths. It really matters little if there is six feet or six thousand feet beneath a swimming fish. An animal living at 10,000 feet depth, however, is greatly influenced by the depth of the water over it. Let's see how.

Water weights 64.6 pounds per cubic foot. A fish doesn't have to swim very far down in the ocean to have a great deal of weight pressing down on it. If the fish has a surface area of one square foot, at a depth of 10 feet the water would be exerting a pressure of 646 pounds per cubic foot. Pressure is the force distributed over the surface of the fish.

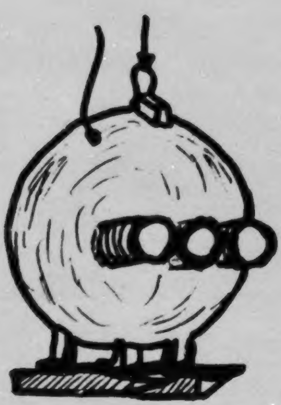
1. How much pressure would be exerted on a fish with one square foot of surface area at the greatest ocean depth?
2. How much pressure would be exerted on each square inch of a fish at the deepest part of the ocean? (Hint: How many square inches in one square foot?)

We often speak of pressure in terms of atmospheres. One atmosphere is equal to the weight of the earth's atmosphere at sea level, about 14.6 pounds per square inch. If you are at sea level, each square inch of your surface is subjected to a force of 14.6 pounds.

3. Mr. Shood B. Flat is six feet tall. He has 2592 square inches of skin surface. What is the total force Mr. Flat is subjected to at sea level?

The pressure increases about one atmosphere for every 10 meters of water depth. At a depth of 5,000 meters, the pressure will be approximately 500 atmospheres or 500 times greater than the pressure Mr. Flat has to deal with. That's a lot of pressure. Let's see just how much.

Dr. William Beebe was a pioneer in deep sea exploration. With support from the National Geographic Society and the New York Zoological Society, Beebe constructed the bathysphere (bathy = deep). In this steel sphere he would be lowered to depths of over 2,500 feet. The thick walled sphere was designed to withstand the great pressures of the ocean deep. The sphere had two thick quartz windows for viewing. On one expedition, Beebe and crew added a third quartz window in the field, sure that their work was as precise as that of the factory.



BATHYSPHERE

To test the new window, the bathysphere, unoccupied, was lowered to 3,000 feet. When the great steel ball was hauled up, Beebe wrote

> " it was apparent that something was very wrong, and as the bathysphere swung clear I saw a needle of water shooting across the face of the port window.
>
> "Weighing much more than she should have, she came over the side and was lowered to the deck. Looking through one of the good windows I could see that she was almost full of water. There were curious ripples on the top of the water, and I knew that the space above was filled with air, but such air as no human being could tolerate for a moment. Unceasingly the thin stream of water and air drove obliquely across the outer face of the quartz. I began to unscrew the giant wingbolt in the center of the door and after the first few turns, a strange high singing came forth, then a fine mist, steam-like in consistency, shot out, a needle of steam, then another and another. This warned me what I should have sensed when I looked through the window, that the contents of the bathysphere were under terrific pressure. I cleared the deck in front of the door of everyone, staff and crew. One motion picture camera was placed on the upper deck and a second one close to, but well to one side of the bathysphere. Carefully, little by little, two of us turned the brass handles, soaked with the spray, and I listened as the high, musical tone of impatient confined elements gradually descended the scale, a quarter tone or less at each slight turn. Realizing what might happen, we leaned back as far as possible from the line of fire.
>
> "Suddenly, without the slightest warning, the bolt was torn from our hands, and the mass of heavy metal shot across the deck like a shell from a gun. The trajectory was almost straight, and the brass bolt hurtled into the steel winch thirty feet across the deck and sheared a half inch notch goughed out by the harder metal. This was followed by a solid cylinder of water, which slackened after a while to a cataract, pouring out of the hole in the door, some air mingled with the water looking like hot steam, instead of compressed air shooting through ice-cold water. If I had been in the way, I would have been decapitated."

Pressures are great, indeed!

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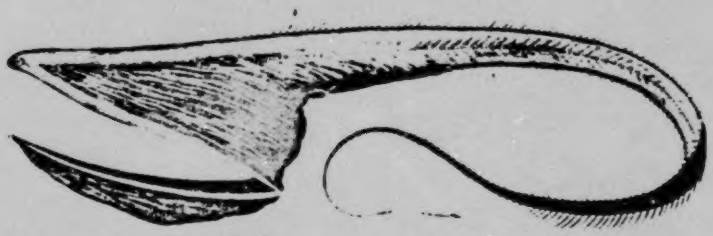
* From Half Mile Down, by William Beebe. Published by Duell Sloan. Pearce (New York) in 1951.

4. What was the pressure exerted on the window per square foot of surface area?
5. The circular window was 1.5 feet in diameter. What was the surface area?
   (Remember that the area of a circle - πr^2 and that $\pi = 3.14$)
6. The window was fastened with 10 one inch bolts. If we assume all bolts held evenly, how much force was distributed to each of the bolts? Surely nothing could live under these great pressures.

In the 1800's scientists hypothesized that life could not exist in the great depths of the ocean. In 1872, H.M.S. *Challenger* sailed from England on a four year investigation of the world's oceans. The *Challenger* expedition found many different kinds of creatures at great depths in the ocean. What might these creatures look like? Would they be flat from the pressure? Tall and thin to avoid the pressure? Spherical to withstand the pressure? Let's see what kinds of deep sea fish the drag nets brought up from the bottom.

Much to everyone's surprise, there were fish of all shapes and styles.



Gulper, or pelican eel (*Eurypharynx pelecanoides*).

A tiny eye is set over a gigantic mouth in this pelican eel or gulper. The gulpers are usually found below 6,500 feet in depth. The large mouth is perched below a brain barely a quarter of an inch long! What evolutionary forces have helped shape this strange fish? First, we must look at the environment in which the gulper lives. Six thousand feet is well below the depth of the sunlit layer of the ocean. The gulper's world is perpetually dark and cold. The number of organisms living in this world is small. Since there is no light, there is almost no plant life. Getting food is a major problem for the inhabitants of this region.

7. Does the gulper have eyes? The eyes are sensitive to light, a fact that makes scientists wonder if angler fish do occasionally move up into the lighted zones of the ocean. Describe an experiment to test the hypothesis that angler fish move up into the lighted ocean zones.

The gulpers are well designed to obtain the food they require. While most dwellers of the deep sea are small, some of the gulpers reach several feet in length. Most of the length, however, is made up by the tail. The body is but a few inches long, and most of the body is comprised of the mouth.

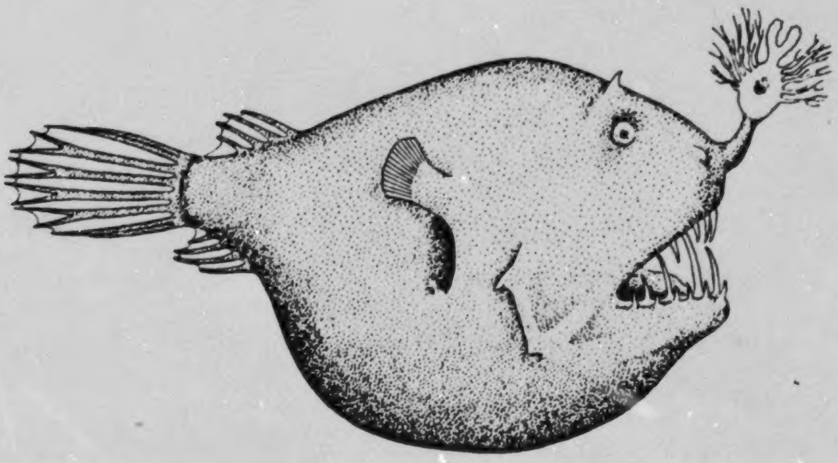
8. Look at the body of the gulper. How do you suppose it obtains food?

No one has ever seen a gulper feed so your hypothesis about feeding might be as good as that of the scientists. We do, however, know a few things. The gulper's mouth is a large, roomy bag. There are a lot of teeth but the soft muscles and thin bones do not seem well adapted to a vicious hunter. The muscles for swallowing are weak. At the end of a whip-like tail there is a reddish light. Like many fish the gulper has a lateral line system, a series of organs/that sense motion located along each side. What do these things suggest?

The gulper, swimming slowly or standing nearly still, slowly sweeps its lighted tail back and forth in the darkness of the ocean deep. What is this moving light? Other fish come to investigate. The gulper can't see these other fish because of the darkness, but it can sense them with its lateral line. The curious prey moves closer. Suddenly, the gulper opens its mouth and gulps the curious fish. The curved teeth grasp the prey and the gulper draws itself over the fish, much like a snake feeding. Using these techniques gulpers can swallow fish larger than themselves.

9. One gulper, caught in a deep sea trawl, had its tail tightly coiled around a small animal in the net. What else does this suggest that the gulper uses his tail for?

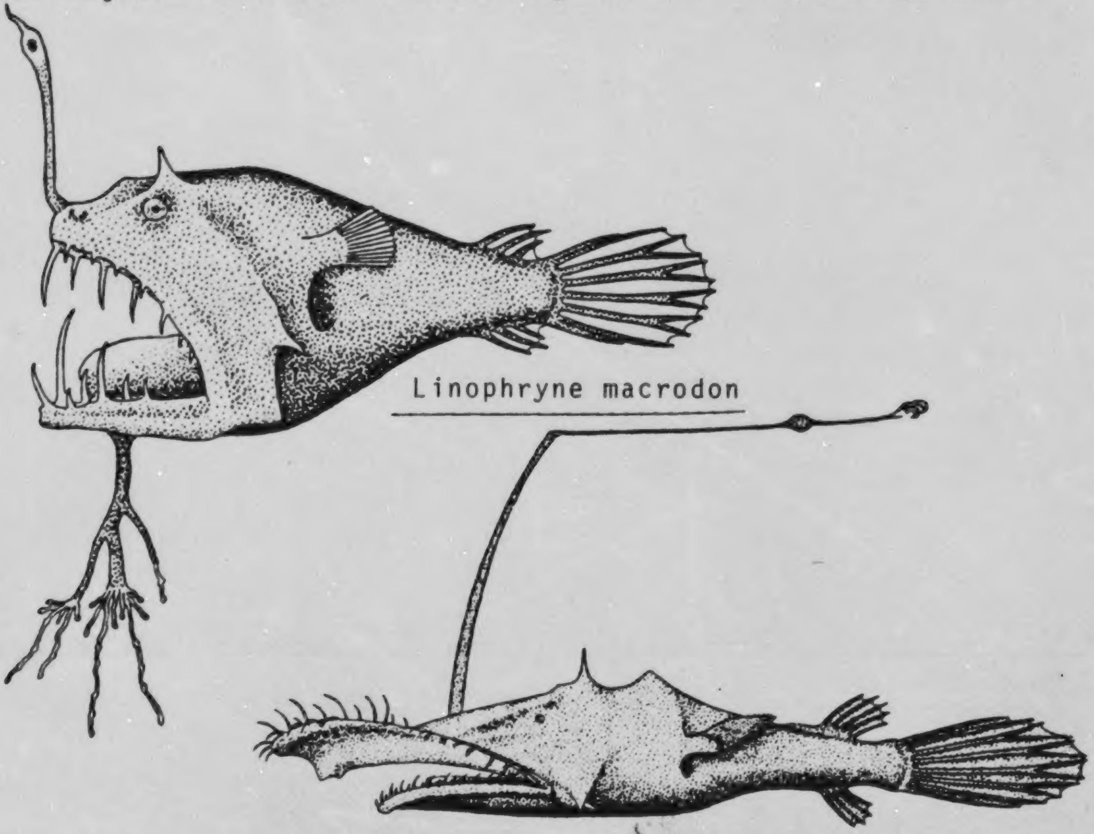
Other deep ocean fish are just as bizarre. The deep sea angler fish lives from 11,500 feet down in the Pacific and Atlantic Oceans.



While this fish looks quite a bit different than the gulper, it shares some things in common. The darkness requires the deep sea angler to use its lateral line system to help detect possible food. The strange structure on the front of the fish glows in the darkness of the depths. The angler wiggles this lure. Again, curious, fish move in to observe. The angler fish moves the "bait" closer to its mouth, the fish follows. Now the mouth yawns open and the fish is pulled into the mouth by the strong suction produced. The teeth fold down and hold the victim. Other sets of teeth move the victim toward the stomach. The huge stomach is able to expand to contain animals almost as big as the angler itself.

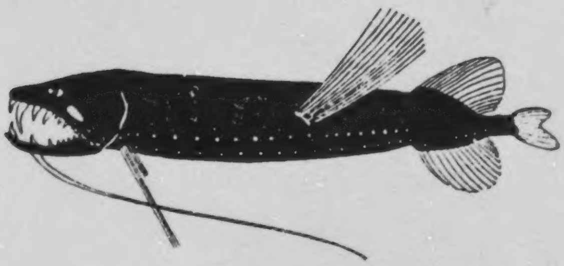
10. Deep sea animals use bioluminescence, the ability to produce light, to attract food. What else might they use this light for?

Other fish found in the depths also have special adaptations. Other anglers have more interesting rod and lure arrangements.



Linophryne macrodon

Lasiognathus saccostoma



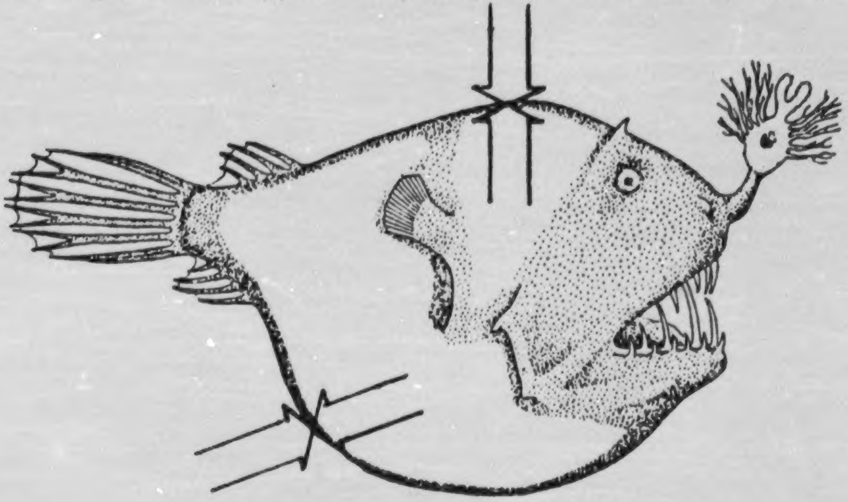
Bothophilus longipinnis

Some deep sea dwellers have rows of lights along the side. The variety within the fishes is great. Evidently these fish can handle the ocean pressure without adopting special shapes. If the answer isn't in the shape, how do these fish withstand the pressure?

Look at the next picture. The fish has just reached the surface after being dragged up some 3,000 feet from the deep ocean.

What is protruding from the mouth? Many fish have an air bladder, a bag full of air that helps them float at different depths. In this picture, the air bladder has been forced out of the mouth. Can this observation give us a clue about how fish withstand the pressures of the deep ocean?

As the fish was brought up the pressure on the outside of the air bladder decreased. The air inside the air bladder, however, was still at the pressure found at 3000 feet. The air expanded inside the bladder as the pressure decreased because pressure and volume of a gas are related. If you increase the pressure, you decrease the volume (Think about squeezing a ballon full of air). If you decrease the pressure, you increase the volume. Decreasing pressure and increasing volume caused the air bladder to expand. How does this help us? The fish was obviously adjusted to the pressure at 3,000 feet. Just as the pressure on the outside of the air bladder was equal to the pressure on the inside of the air bladder, the pressure on the inside of each cell pressing outward was equal to the pressure of the water on the outside of the cells. The fluids in the cells make an equal but opposite pressure. The fish can be any shape.



EQUAL PRESSURES

11. If the fish swims upward, what must happen to the pressure pushing outward in each cell?

So, how do creatures living in the great depths of the ocean withstand the pressure? They create an equal but opposite pressure within themselves to maintain their shape. Very clever.

Life in the deep ocean is very interesting. Creatures living in the deep oceans face lots of problems. They have evolved many unique ways to deal with these problems.

To learn more read: Abyss by C.P. Idyll, published by Thomas Y. Crowell, New York (1964).

TEACHER BACKGROUND - Man Underboard!

"Man Underboard!" expands upon some of the concepts introduced in "The Pressure's On" by placing man into the ocean depths. While man has descended far into the ocean in special apparatus like the bathysphere, man is effectively limited to a shallow band at the surface if he is to spend long periods or do much real work in the oceans. Man has not evolved the physiological adaptations necessary to recolonize the sea. We have, however, compensated for our physiological shortcomings through the development and construction of mechanical hardware such as SCUBA gear.

Duplicate the activity pages. One set is recommended per student. This activity is best accomplished on an individual basis with group or class discussion as a follow-up. Upon completion, allow time for discussion and review of the correct answers.

KEY

1. The percentage of the deepest ocean scuba divers can explore before they become useless is:

   $$\frac{\text{250 feet useless depth}}{\text{36,200 deepest spot}} \times 100 = .69\%.$$

   In scuba gear, man can safely explore less than 1% of the ocean depths. Even so, scuba has given man a real tool for ocean exploration.

2. At a depth of 30 meters, a pressure of 3 atmospheres is forcing the nitrogen into the bloodstream. At 75 meters, a pressure of 7.5 meters is forcing the nitrogen to dissolve in the bloodstream.

3. The symptoms of caisson disease are pain in the joints sometimes followed by paralysis, blindness, dizziness, unconsciousness and convulsions, air emboli, asphyzia and even death. The cause is a release of nitrogen bubbles in the bloodstream due to a rapid reduction in pressure.

4. A skilled diver can safely work at 100 feet without stage decompressing on her return to the surface for 25 minutes.
5. To be totally at home in the marine environment, man must conquer:
   a. caisson's disease or the changes due to pressure differences
   b. breathing in an aquatic environment.
   c. Maintaining a constant body temperature in a medium (water) that conducts heat away from the body at a much faster rate,
   d. eating in an aquatic environment.,

   Other problems are possible. Two problems are required.
6. Designs will vary. Most people will transplant a piece of our terrestrial environment into the aquatic world. This is, in fact, the approach we have used in both our deep sea exploration and our deep space exploration programs. Reward creative solutions to the problems posed. Use this question to stimulate thought and discussion on future environments, a subject which will be dealt with in later activities.

KEY WORDS

air emboli

asphyxia

atmosphere

bends

caisson disease

convulsions

decompression sickness

gills

narcotic

nitrogen

nitrogen narcosis

oxygen

pressure

scuba

stage decompression

stupor

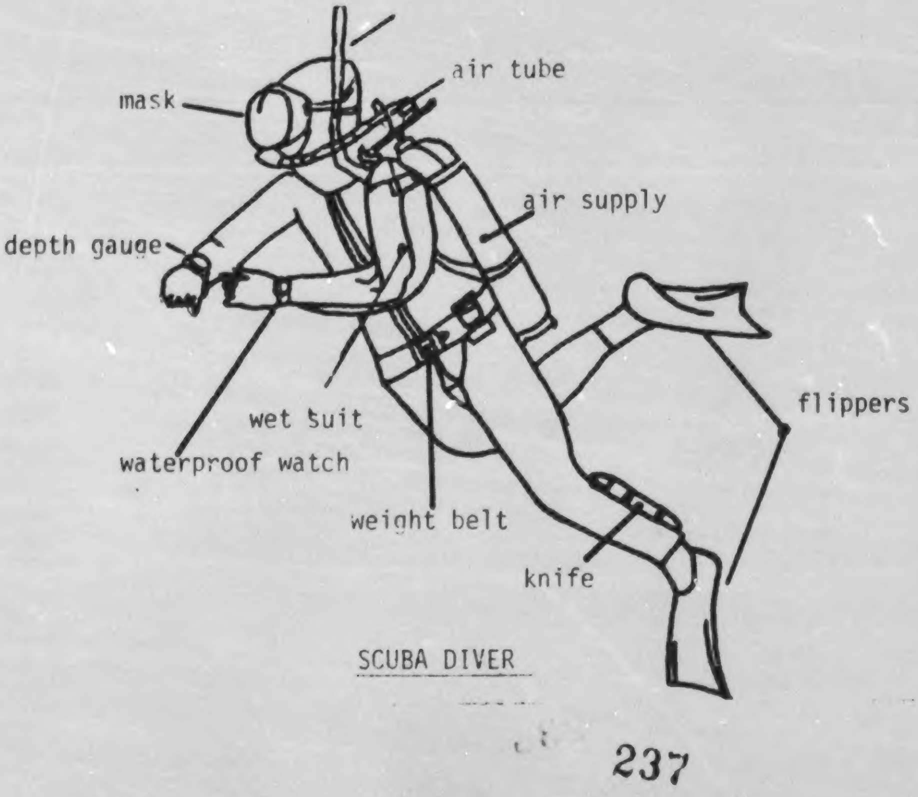
symptoms

MAN UNDERBOARD!

What happens to man when he enters the world of water? Do our cells adjust to the changes of pressure? Let's take a look and see. The average scuba diver becomes useless at about 250 feet of depth (he often becomes worse than useless, he becomes a hazard) a far cry from the 11,500 foot depth at which we find the angler fish fishing. What happens to man as he descends into the ocean?

1. The deepest spot discovered is 36,200 feet. What percentage of this depth can scuba divers explore before they become useless?

We need oxygen to survive. Oxygen makes up about 21% of the air we breathe. About 78 per-cent of the air we breathe is nitrogen gas. Nitrogen is relatively inert, it is more or less chemically inactive. The oxygen and nitrogen are carried in the bloodstream. At sea level the nitrogen presents no problem for man. But what happens to these gases as we descend into the ocean depths.



SCUBA DIVER

The increased pressure allows more oxygen and more nitrogen to dissolve into the blood. A strange thing now happens. At about 100 feet the pressure will cause enough nitrogen to dissolve in the blood for the nitrogen to become a dangerous drug, a narcotic. Nitrogen narcosis eventually results in stupor and sleep (not a good condition 100 feet below the surface). Before the stupor stage, divers become dizzy, their ability to make even simple mental decisions (like tell time) is reduced, sometimes they decide they no longer need to breathe through their mouthpiece. The precise symptoms and the depths at which the symptoms appear vary with each individual and with each dive. Diving below 100 feet requires special skills and is dangerous. Returning to the surface reduces the nitrogen content and reduces the symptoms.

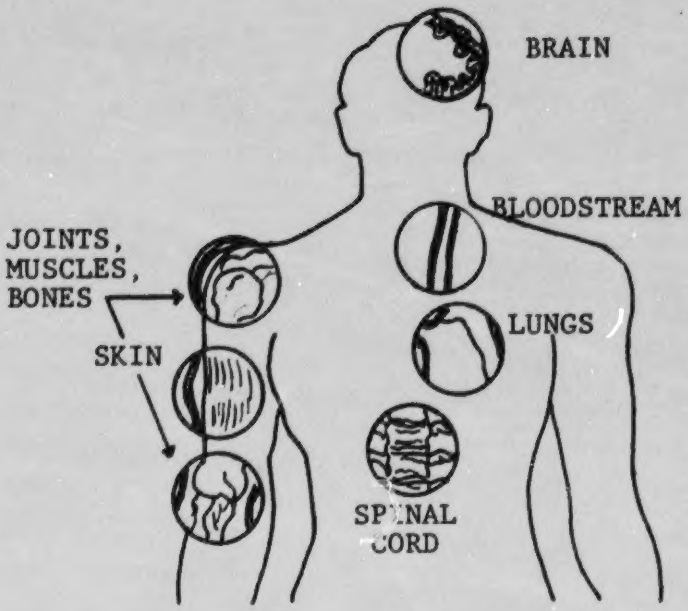
2. We have seen that one atmosphere equals about 14.6 pounds per square inch pressure. The pressure increases 1 atmosphere for every 10 meters of depth. How many atmospheres are forcing the nitrogen into the blood stream at 30 meters (about 100 feet)? at 75 meters (about 250 feet)?

Nitrogen narcosis is not the only problem human divers face. Interestingly enough the second major danger faced by divers was not discovered beneath the water's surface. The 19th century was a period of rapid industrial expansion. Roads were needed to carry manufactured goods. Some of these roads needed to cross rivers. In some cases, engineers decided going under the river was better than building a bridge over it. As the tunnel builders worked, the tunnels were pressurized to keep the water in the river from flowing into the working areas. At the end of the day's work, the workers surfaced to ordinary atmospheric pressure. Many of the workers developed pain in their joints. Some became paralyzed. Their symptoms were given the name "caisson disease" (A caisson is a watertight enclosure inside which men can do construction work under water).

The symptoms were recognized and the disease had a name. The causes, however, remained a mystery. In 1907 Dr. J.S. Haldane discovered a way to prevent the disease. By placing the sufferer in a pressurized room and gradually reducing the pressure, the disease did not occur. Now a way to prevent the disease was known, but the cause was still uncertain.

Maybe we should open some champagne to celebrate the cure? Pop! Out flys the cork. "Eureka, I have it! The cause of the disease!" The cork flys out because the gas in the champagne bottle is under pressure. The pressure is released and the gas in the champagne bubbles out. The nitrogen in the blood stream is also under pressure. A quick rise to the surface is just like popping the cork. The pressure is released and the nitrogen in the bloodstream forms bubbles. "Carbonated blood" affects the whole body. Bubbles in the brain tissue can cause blindness, dizziness, paralysis, unconsciousness and convulsions. Extreme pain is experienced in the joints and muscles as the bubbles form. The bubbles can cause air emboli which block the circulation. Bubbles in the spinal cord can cause paralysis of legs and arms. Asphyxia (lack of oxygen) and choking are signs of bubbles in the lungs. Severe cases can result in death.

3. What are the symptons and the cause of caisson disease?


BRAIN
BLOODSTREAM
JOINTS, MUSCLES, BONES
LUNGS
SKIN
SPINAL CORD

Caisson disease is now also called decompression sickness or the bends. Divers can avoid the disease by limiting the time and depth of their dives. Coming to the surface in stages (stage decompression) with a pause at each stage allows the nitrogen to diffuse out of the blood. The length of time a diver can stay at a certain depth without stage decompressing decreases with depth.

Depth (feet)	No-decompression limits (min)
10	
15	
20	
25	
30	
35	310
40	200
50	100
60	60
70	50
80	40
90	30
100	25
110	20
120	15
130	10
140	10
150	5
160	5
170	5
180	5
190	5

4. How long can a skilled diver safely work at a depth of 100 feet without having to stage decompress?

We differ from fish and most other aquatic animals in that we breathe using lungs rather than gills. Even so, aquatic animals including whales and other diving mammals must deal with the problems of dissolved gases. The aquatic animals have evolved mechanisms to handle these problems that we face. Man is not yet able to be totally at home in the marine environment.

5. To be totally at home in the marine environment, what are two problems man must conquer?
6. Design a system that will enable man to overcome the two problems you stated in question number 5.

PHYSICAL FACTORS: The Water Solution

TEACHER BACKGROUND - In the Soup

"In the Soup" is an introduction to the chemical properties of sea water. It also serves to introduce the several activities which follow. Sea water chemistry is a broad and important field which can only be touched on briefly in a unit such as this. Detailed Teacher Backgroumd sections, student text sections and student activity sections are included for some of the most common chemical analysis. Additional chemical determinations can be found in the references cited below so that you may expand your treatment of sea water if you so desire. Since access to both sea water and equipment varies, you can tailor your treatment to your particular requirements and situation. Proximity to the sea is nice but not necessary to accomplish these activities. Artificial sea water may be made using the recipe given later or by purchasing sea salts and following the manufacturer's directions. To minimize problems, preview the activities before you do them.

Duplicate the activity pages for "In the Soup". One set is recommended per student. These pages lend themselves to individual work and may be accomplished as homework. Small group discussion of the questions may prove valuable. Allow time to review the material and the text questions with the entire group. Review the next activities you plan to use and collect any of the materials or equipment you might be lacking.

KEY

1. If ice sank, the lake would freeze solid from bottom to top! The problems inherent in this situation for aquatic organisms are obvious. Additional physical characteristics of water are included in this teacher background.
2. If all of the sodium and chlorine were to combine 8.42 parts of chlorine per thousand parts of water would be left over (i.e.(18.98 o/oo Ci^- - (10.56 o/oo Na) 8.42 o/oo Cl^-)

3. (Sodium = 30.62% + (Chlorine = 55.07%) = 85.69% of the saltiness is due to the presence of sodium and chlorine.
4. This question provides a good opportunity to discuss scientific notation. (Please see appendix "Scientific Notation").

   The answer may be derived as follows:

$$\frac{.0000000004 \text{ parts gold}}{1000 \text{ parts of water}} \times 1{,}000{,}000 \text{ tons of seawater} =$$

$$\frac{4 \times 10 -10 \text{ parts gold}}{1 \times 10^3 \text{ parts water}} \times \frac{1 \times 10^6 \text{ tons of seawater}}{1} =$$

$$4 \times 10^{-7} \text{ tons of gold} =$$

$$.0000004 \text{ tons of gold.}$$

Note that .0000004 tons of gold is .0008 pounds or .0128 ounces. For an interesting account of mining gold from sea water you might choose to read the following short story to your students:

"The Man Who Ploughed the Sea" in Prelude to Mars by Arthur C. Clarke. Published by Harcourt and Brace in 1965.

5. The explanation is more important than the answer. The liquid of life, perhaps is not one liquid but several.

KEY WORDS

atoms

chlorine

combustible

concentration

constituents

dissolved

elements

evolved

hydrogen

molecules

organic material

oxygen

relative percentage

sodium

solvent

Analytical Procedures:

Analytical procedures have been selected for high school students of varying abilities and background experiences. Experience has shown students with little or no chemistry background often perform admirably with some initial supervision in laboratory techniques and an understanding of concentration and the units of concentration. It is desirable that students understand the theory and mechanics of the reaction themselves, however, it is not a requirement if the objectives center on the data and the application of the data to the marine environment. Wherever possible it is recommended that the students:

1. Inventory chemistry
2. Determine order and reorder needs
3. Assist with ordering
4. Determine and make up needed quantities of reagents
5. Conduct calibration and standardizations called for in procedures
6. Adhere as closely as possible to recommended procedures.

Selection of these specific procedures has been made with an attempt to use the most current up to date techniques with the following criteria in mind:

1. Availability of equipment
2. Equipment and reagent costs
3. Compatability of optical procedures with the Bausch & Lamb Spectronic 20
4. Student time limitations (typically one hour) every 24 hours
5. A minimum of chemical interferences
6. Desirability of parameters to be monitored

THE FOLLOWING BOOKS ARE MOST HELPFUL:

Greenberg, Arnold, et al., editors. Standard Methods for the Examination of Water and Wastewater. 14th edition, 1975.

Hazen, James, Introduction to Spectroscopy. Bausch & Lomb #S-4036.

Martin, Dean, Marine Chemistry Vol. 1 & 2. 1972. Strickland, J.D.H. & Parsons, T.R., A Practical Handbook of Seawater Analysis. 1972.

Sverdrup, H.U., Johnson, Martin W., & Fleming, Richard H., The Oceans 1942.

Artificial Sea Water

If you do not have immediate access to natural sea water, you can prepare artificial sea water using one of the receipes below.

Number 1.

Dissolve:

310 g of analytical reagent quality sodium chloride, NaCL,
100 g of analytical reagent quality magnesium sulphate, $MgSO_4.7H_2O$,
and 0.50 go of sodium bicarbonate, $NaHCO_3.H_2O$
in 10 liters of distilled water.

Number 2.

Dissolve:

24.7 g of sodium chloride,
13.0 g of $MgCL_2 \cdot 6H_2O$ and
9.0 g of $Na_2SO_4 \cdot 10H_2O$
in 954 ml of distilled water

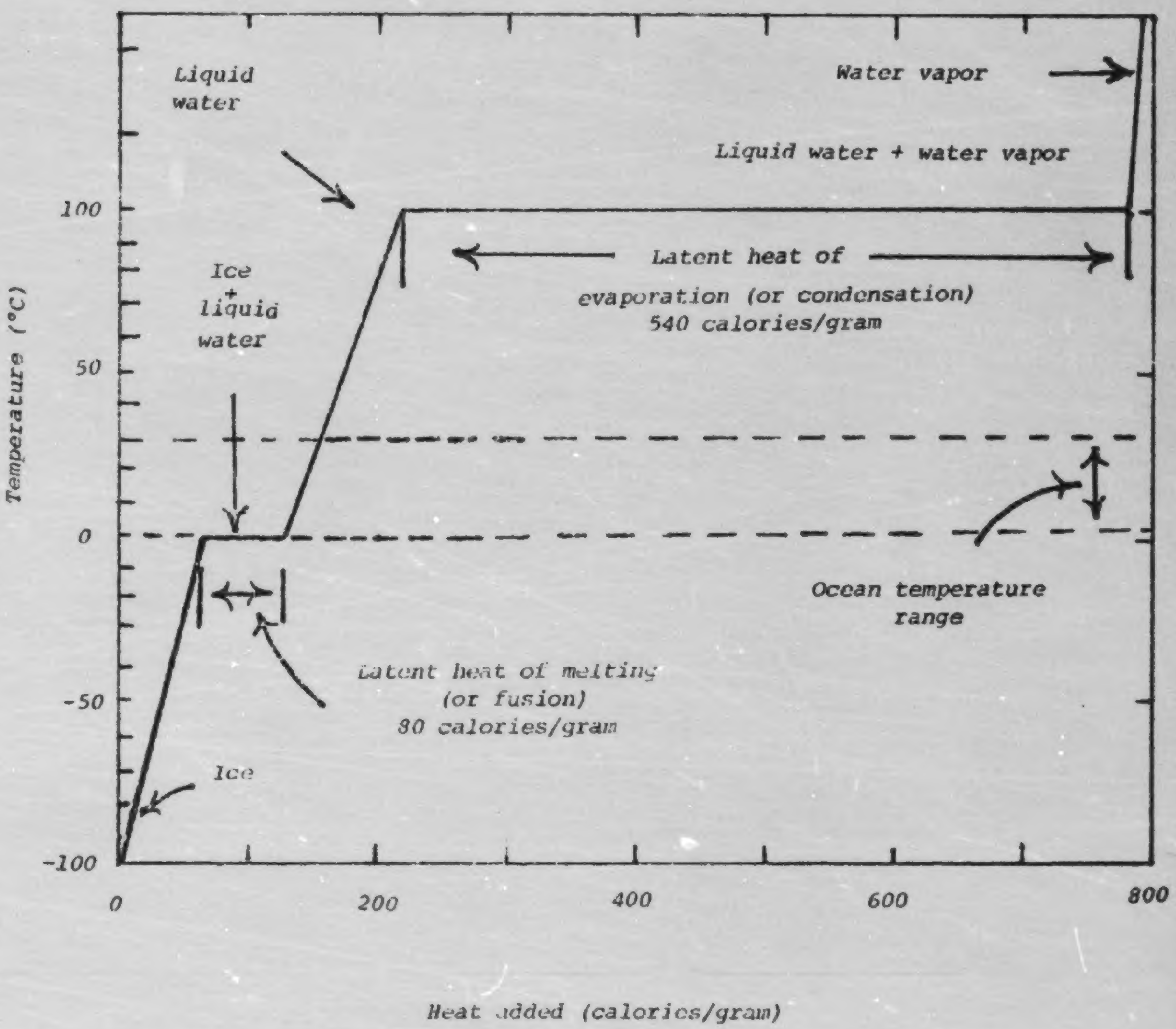
One kilogram of this solution contains
0.478 mole of sodium;
0.064 mole of magnesium;
0.550 mole of chloride; and,
0.028 mole of sulfate.

The water we take so much for granted is a truly incredible substance. The following pages outline some of the unique properties of water.

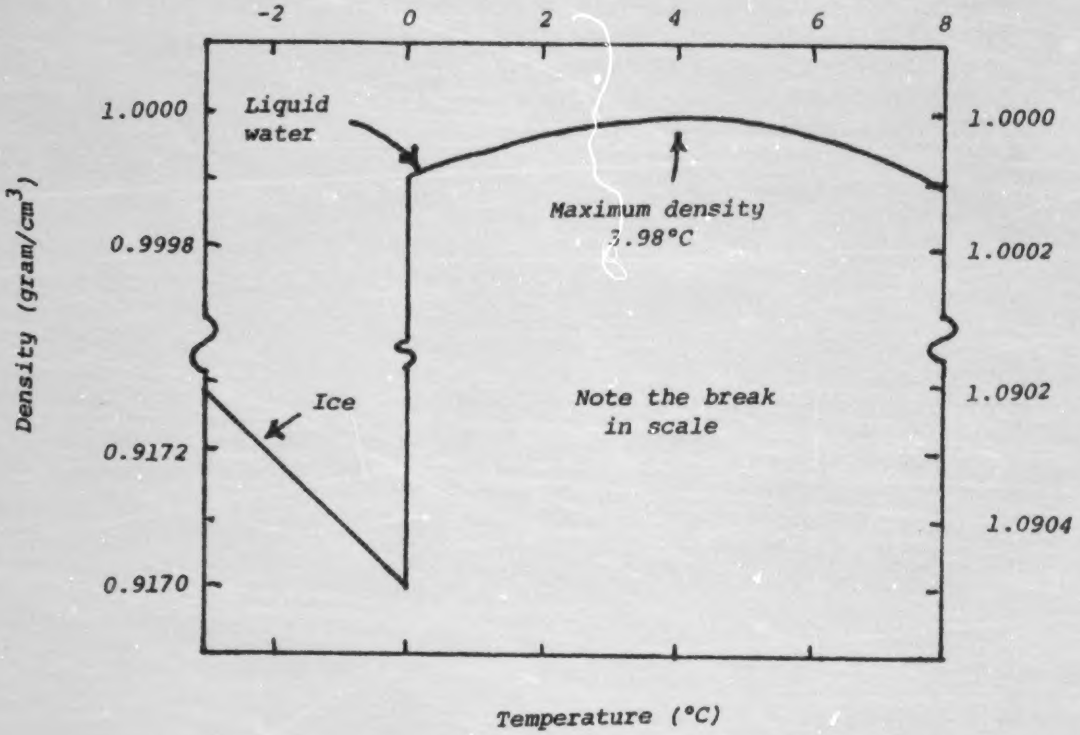
CERTAIN PHYSICAL PROPERTIES OF WATER

Property	Comparison with other substances	Importance in physical-biological environment
Heat capacity	Highest of all solids and liquids except liquid NH_3	Prevents extreme ranges in temperature. Heat transfer by water movements is very large. Tends to maintain uniform body temperatures.
Latent heat of fusion	Highest except NH_3	Thermostatic effect at freezing point owing to absorption or release of latent heat.
Latent heat of evaporation	Highest of all substances	Large latent heat of evaporation extremely important in heat and water transfer of atmosphere.
Thermal expansion	Temperature of maximum density decreases with increasing salinity. For pure water it is 4°C.	Fresh water and dilute sea water have their maximum density at temperatures above the freezing point. This property plays an important part in controlling temperature distribution and vertical circulation in lakes.
Surface tension	Highest of all liquids	Important in physiology of the cell. Controls certain surface phenomena and drop formation and behavior.
Dissolving power	In general dissolves more substances and in greater quantities than any other liquid.	Obvious implication in both physical and biological phenomena.
Dielectric constant	Pure water has the highest of all liquids	Of utmost importance in behavior of inorganic dissolved substances because of resulting high dissociation.
Electrolytic dissociation	Very small	A neutral substance, yet contains both H^+ and OH^- ions.
Transparency	Relatively great	Absorption of radiant energy is large in infra-red and ultraviolet. In visible portions of energy spectrum there is relatively little selective absorption, hence is "colorless". Characteristic absorption important in physical and biological phenomena.
Conduction of heat	Highest of all liquids	Although important on small scale, as in living cells, the molecular processes are far outweighed by eddy conduction.

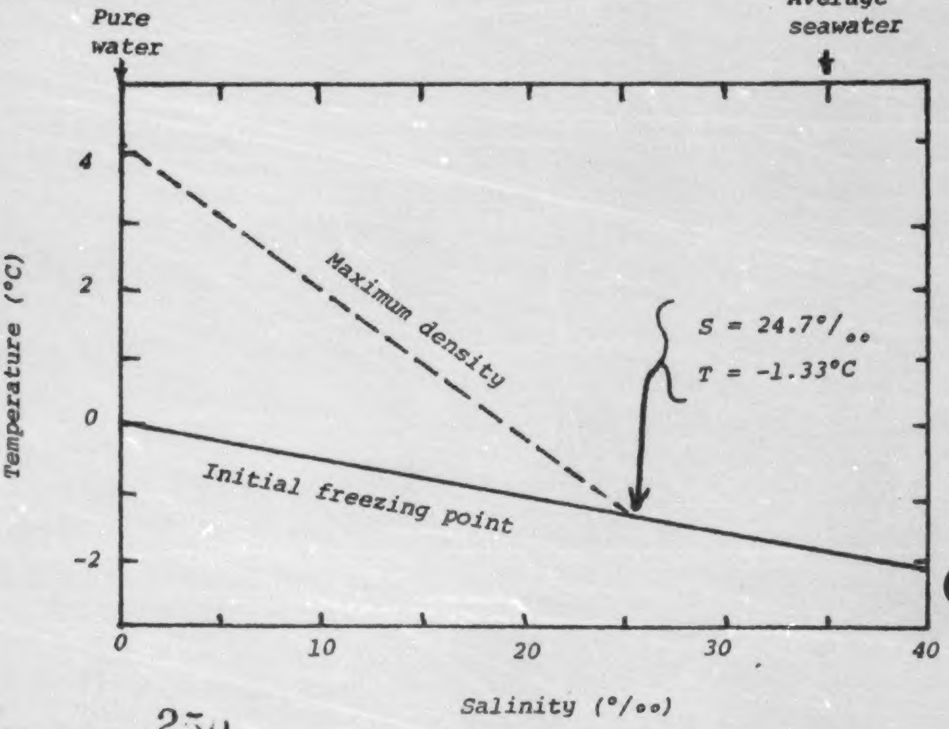
Changes in temperature when heat is added (or removed) from ice, liquid water, or water vapor. Note that the temperature does not change when mixtures of ice and liquid water or liquid water and water vapor are present.



Effect of temperature on density (grams/cubic centimeter) and specific volume (cubic centimeters/gram) of ice and pure liquid water.



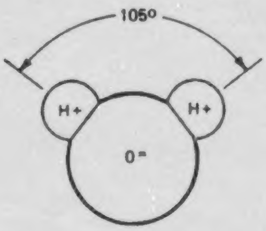
Effect of salinity on the temperature of maximum density and the initial freezing point of seawater.



IN THE SOUP

What is the liquid of life? Blood? Water? Sea water? All three? Water is what makes life on our earth possible. Sea water is water with metals, organic material and gases dissolved in it. Blood is water with metals, organic material and gases dissolved in it. Hmmm? Sounds a bit like sea water. Let's look at all three.

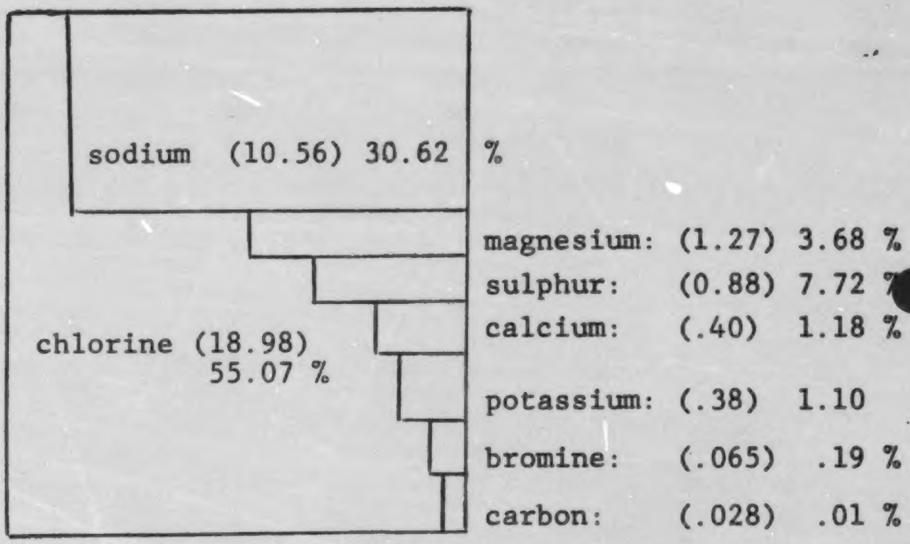
We know that all matter is composed of atoms. We also know that water is made up of molecules composed of one atom of oxygen (O) and two atoms of hydrogen (H). We write water H_2O. Two atoms of an explosive gas (hydrogen) and one of a combustible gas (oxygen) make a liquid used to put out fires! Water is one of the most interesting liquids known. Most substances become more dense as they change from a liquid to a solid. Water, however, is most dense at four degrees Celsius, just before the freezing point. Water is also able to dissolve more substances than most other liquids. The remarkable solvent (ability to dissolve things) properties of water are due to the way the atoms are arranged. The diagram below shows how the two hydrogen atoms and the one oxygen atom are joined. This arrangement tends to let water molecules combine strongly with each other as well as with molecules of other substances.



1. The temperature has dropped to zero. Lake Solid forms a thin layer of ice on the surface. What will happen to the lake if the temperature remains the same and ice sinks instead of floats?

The fact that water is able to dissolve so many things is the reason we have sea water. The saltwater we find in the oceans has atoms of most of the elements dissolved in it. Not everything dissolves to the same degree. The following graph shows the most common materials dissolved in sea water.

Materials In Seawater In Parts Per Thousand (0/00) And
In Percent (%) By Weight



These eight major constituents comprise over 99% of the substances found in sea water. The remaining elements found in sea water are found in concentrations less than one part of the substance per million parts of water. All life in the sea depends upon sea water in many ways.

2. Sodium and chlorine can combine to form table salt, sodium chloride. If all of the sodium and chlorine were to combine to form table salt, how much of which element would be left over?

3. What percent of the saltiness of sea water is due to sodium and chlorine? Please show your work.

4. Gold is found in a concentration of .0000000004 parts per thousand parts of water. How many tons of gold would you be able to mine from 1 million (1,000,000) tons of sea water? Please show your work.

So, is saltwater the liquid of life? What about blood? Interestingly enough, blood looks very much like sea water. We find the same kinds of materials and in about the same relative percentages. The total amounts of materials are less but the kinds of materials are the same. This observation has led scientists to think that our blood evolved as a kind of enclosed sea water to keep our tissues wet and healthy. To these scientists, when we look at blood today we are looking at the sea water concentrations of the oceans of millions of years ago. If this theory is true, man and other animals moved from the ocean waters by taking the ocean waters with them in the form of blood. Our bloodstream plays much the same role as diver's scuba gear - it lets us live and function in a hostile environment.

5. Which liquid, then, is the liquid of life? Explain and justify your choice.

TEACHER BACKGROUND - Salinity

The most obvious difference between "fresh water" and "sea water" environments is the salt. The activities which follow give your students background on the salinity of the oceans and culminate with the experimental determination of the salinity of sea water samples.

This investigation requires some specialized equipment that you may have to borrow. Hydrometers are available in aquarium shops for a reasonable sum. They can also usually be borrowed from chemistry teachers. This is a good chance for some integretaion in your curriculum! If you can only obtain one or two hydrometers, fear not. You can have the students work on the activity "Salt II" simultaneousl Small groups can use the hydrometer. If you do not feel comfortable with this approach, you can do the activity as a demonstration. Provide the data and stimulate discussion through questions. Avoid answering all of the questions at this time.

Part II uses the data gathered in Part I but treats it in a slightly different manner. The two approaches may give slightly different results. This situation can provide an opportunity for a discussion of precision - just how precise do you need to be in determining salinity? The answer, of course, depends upon what you plan to do with the data once you have it in hand.

Ideally you will obtain two water samples using a device like that shown on the next page. One sample should come from 1 meter below the surface and the second should come from the bottom. If you cannot obtain the samples in this manner you can still use the activit by making your own salt water samples. For the top sample, dissolve 29 grams of table salt (sodium chloride) in 1 liter (100 ml) of tap water. The bottom sample can be made by dissolving 31 grams of table salt (sodium chloride) in one liter (100 ml) of tap water.

Duplicate the activity pages. One set per student is recommended. Hydrometers require careful handling. At the conclusion of the investigation, allow time for a discussion of the results and questions.

KEY

1. Chlorine is the element found in greatest abundance (55.0%). The first two questions are to encourage use of the figures in the text.

2. One would find 35 parts of salt per 1000 parts of water (35 o/oo) in the sea water shown in the figure.

3. The ocean will be more saline because of the continual leaching of dissolvable minerals. The salts dissolved in sea water are not at saturation, more can be dissolved in the water solution. It is interesting to note that although the salts are not saturated, they do not remain indefinitely in the water solution due to various biological and chemical processes. The amount of time a substance remains in the sea water solution is called its residence time.

4. a. The salinity is the greatest at seven to eight meters in depth.

   b. The salinity was the least at one to two meters in depth.

5. The salinity calculation is set up in the same manner as that shown in the text:

$$20 \text{ o/oo chlorides} = 55.0\% \text{ of the total salinity;}$$

$$20 \text{ o/oo chlorides} = .550 \times (\text{total salinity})$$

$$\frac{20 \text{ o/oo chlorides}}{.550} = (\text{total salinity})$$

$$36.3 \text{ o/oo} = \text{total salinity}$$

6. Since the water is without salts, the inside and outside concentrations will never equal as long as the jellyfish remains intact.

7. The jellyfish will eventually burst. The distilled water became a salt solution eventually approximating the concentration in the cells. This procedure has been abandonded but can be used as an illustration of the importance of osmotic balance.

8. The shrinking of the jellyfish will stop when the salt concentration on the inside equals that of the water surrounding the jellyfish.

KEY WORDS

average

bouyancy

chloride ion

concentration

density

density-water temperature chart

dissolve

elements

estimate

estuaries

freshwater

graduated cylinder

halocline

hydrometer

internal ratio

leaching

parts per thousand (o/oo)

salinity

salinity-corrected density chart

salinity preference

tolerance

variation

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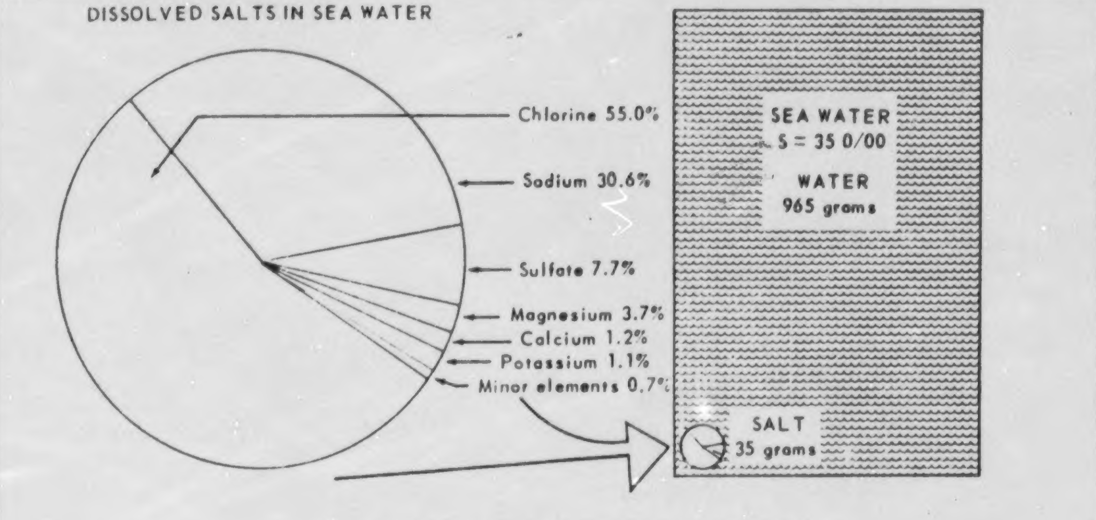
Hull, Seabrook, 1964, The Bountiful Sea, Prentice Hall: New York.

Standard Methods for the Examination of Water and Wastewater, 1965, Twelfth Edition, APHA, AWWA, & FSIWA: New York.

SALINITY

Sea water contains a mixture of minerals, mostly salts. If you evaporate a sample of sea water, you end up with most of the elements known to man. Yet more than 99 percent of the sea salts are made up of only six elements: chlorine, sodium, magnesium, sulfur, calcium, and potassium. These salts are the fertilizers of the sea. They are necessary for animal and plant growth.

DISSOLVED SALTS IN SEA WATER



Relative proportion of water and dissolved salts in sea water.

1. Which element is found in the greatest abundance in sea water?

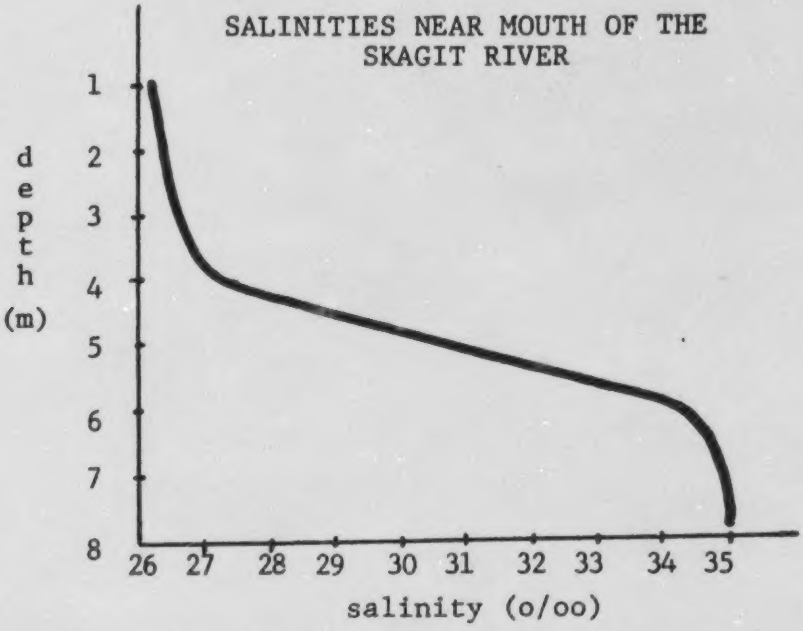
2. The symbol o/oo means parts per thousand. How many parts of salt per thousand parts of water would you find in the sea water shown in the figure above?

The dissolved minerals or salts are still being added to the oceans. Rain waters flow over the land, leaching dissolvable minerals and depositing them in the oceans. The normal salinity (total amount of dissolved salts) of sea water is 35 parts per thousand (written as S = 35 o/oo). This notation means that there are 35 grams of dissolved salts per 1000 grams of sea water. It also means that there are 35 tons of salt per 1000 tons of sea water.

3. In a hundred thousand years, would you expect the salinity of the oceans to be less than, equal to, or greater than it is now? Why?

While the salinity variation is small in the oceans, the saltiness of sea water can vary considerably in areas such as estuaries and bays that are supplied with fresh water from rivers, streams or runoff. Plants and animals need special adaptations to withstand the changes of salinity found in estuaries. Seasonal variation in the fresh water flows from rivers which feed into such areas is one of the major causes of the fluctuation in salinity. Fresh water flow can also account for different levels of water having different salinities. The incoming flow may be concentrated at a certain level due to temperature or density differences. When testing for salinity levels in estuarine situations, samples must be taken at several depths.

4. Fresh water is less dense than salt water. How can this observation explain the following results obtained near the mouth of the Skagit river?


SALINITIES NEAR MOUTH OF THE SKAGIT RIVER

a. Where was the salinity the greatest?

b. Where was the salinity the least?

c. The zone of rapid change is called the halocline (halo = salt + cline = change, slope). Label the halocline on the above graph.

Although salinity may vary slightly from ocean to ocean, the internal ratio of salts is always constant. In other words, whether the salinity is 32 o/oo or 35 o/oo we would find that 55.0% of the salts were chlorides. If the ratio of salts is always the same, we only need to determine the concentration of one of the elements present to know the concentration of all of the elements. The total of these concentrations is the salinity. Usually the chloride ion (Cl-) is the element that is measured when this procedure is used. For example, if the water sample has 19 parts of chloride per 1000 parts of water, the overall salinity will be approximately 34 1/2 o/oo. How did we arrive at that figure?

Well, 19 o/oo chlorides = 55.0% of the total salinity;

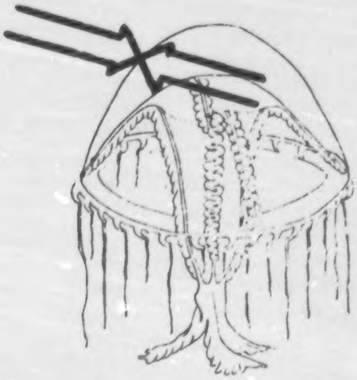
or, 19 o/oo chlorides = .550 x (total salinity);

or, $\frac{\text{19 o/oo chlorides}}{.550}$ = (total salinity).

or, 34.5 o/oo = total salinity.

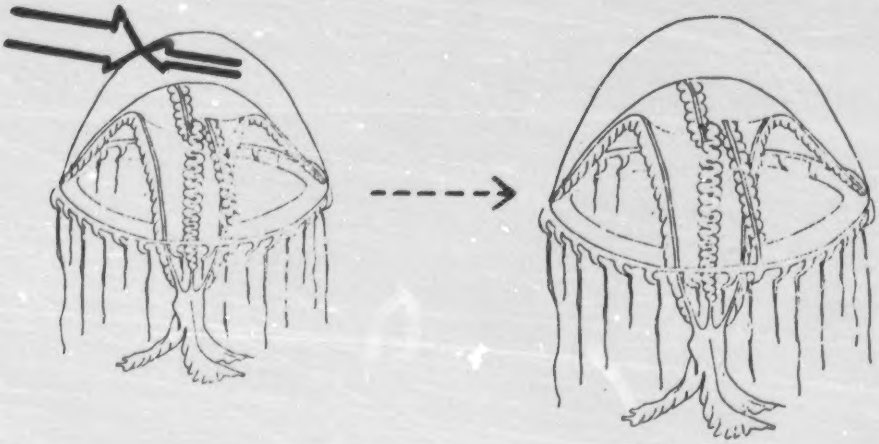
5. What would be the salinity of a sample having 20 o/oo chlorides? Please show your work.

How does salinity affect living things? Living cells are largely water with a few dissolved salts and other materials. The materials inside the cell, for the most part, stay there. Water, however, can move into and out of the cell. How is this important? In living cells the water tends to move into or out of the cell until the concentration of salts "salinity" inside the cell equals the concentration of salts outside the cell. What does this mean? Let's look at a jelly fish and see. Our jelly fish is floating peacefully in the sea. The salt concentration within its cells is equal to the salt concentration in the water around it. The same amount of water enters its cells as leaves them.



WATER IN = WATER OUT

Poor jellyfish! Its collected by Mr. Outofit's oceanography class. Mr. Outofit places the jellyfish in a freshwater aquarium. The salt concentration within the cells of the jellyfish is now greater than the salt concentration in the distilled water of the aquarium. The salt can't move out of the jellyfish. In an effort to equalize the concentrations, water begins to move into the cells of the jellyfish. The concentration of salts in the cells is reduced but its still higher than in the water. More water moves into the jellyfish and the jelly fish begins to swell.

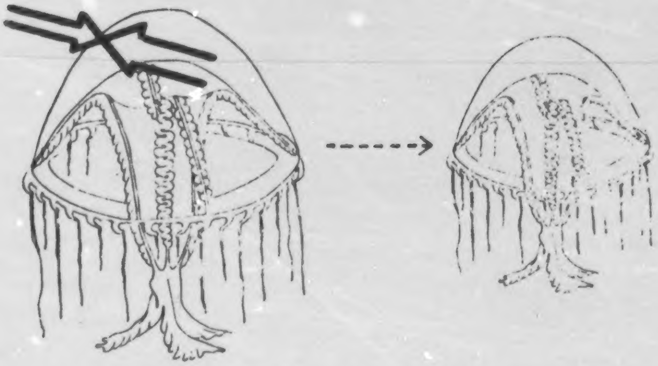


WATER IN IS GREATER THAN WATER OUT

6. Will the concentration on the outside ever equal the concentration on the inside of the jellyfish?

7. What will eventually happen to our jellyfish?

Mr. Outofit is panicked! Thanking quickly he grabs the jellyfish and moves it into a tank of salt water. Unfortunately for our jellyfish, the salt concentration is 70 o/oo about twice what its used to. Now what will happen? Again, the salt can't move out of the jellyfish. How can the inside and outside concentrations be made more equal? This time water moves from the jellyfish into the water. This movement of water makes the salt inside of the cells more concentrated and makes the outside water slightly less concentrated. Our poor jellyfish begins to shrink as it loses water. This shrinking is called dehydration.



WATER IN IS LESS THAN WATER OUT

8. When will the shrinking of our jellyfish stop?

The movement of water into and out of cells is called osmosis. In real animals the situation is more complex than that shown above. Animals and plants have developed mechanisms to handle the small changes in salinity that normally occur where they live. Drastic changes in salinity however, cannot be dealt with and the cells of the animal or plant behave like those of our imaginary jellyfish.

How is salinity determined? In the following experiment you will have a chance to perform one technique commonly used for the determination of salinity.

TEACHER BACKGROUND - The Determination of Salinity - Hydrometer Method

The hydrometer is a standard tool for the rapid determination of the salinity of a water sample. The density of the water determines how high the hydrometer floats. A scale has been inserted into the hydrometer for ease of reference. It is possible to have your students make their own hydrometers. Since the salty taste is the most obvious difference between fresh water and salt water, the determination of salinity is a good place to begin a look at the things that make saltwater "salty".

Duplicate the activity pages. One set is recommended per student. This activity is best performed by small groups. The number of students working in a group depends upon the number of hydrometers available. Hydrometers are available in aquarium shops for a resonable sum. They can also usually be found in chemistry rooms. Borrowing equipment provides a good chance to let others know what is happening in your class. If you can only obtain one or two hydrometers, fear not. You can have your students work simultaneously on the activity "Salt II". If you do not feel comfortable with this approach, you can do the activity as a demonstration. Provide the data and stimulate disucssion through questions. Let your students then answer the questions in the activity using the data you provide through your demonstration. The demonstration approach is less desirable than having your students perform the activity but much more desirable than omitting the activity entirely. Ideally you will obtain two water samples using a water sampling device such as a Van Dorn bottle. One sample should come from 1 meter below the surface and the second should come from the bottom. If you cannot obtain the samples in this manner, you can still use the activity by making your own salt water samples using one of the recipes given previously in "In the Soup". Hydrometers are fragile. Caution your students and demonstrate their care and handling. Provide any assistance necessary during the investigation. Circulate between groups to be sure everyone understands the procedure. Allow time for clean up. After the activity is completed, plan to spend time in a discussion of the results and their interpretation while providing answers to the questions found within the activity.

KEY

Interpretation and Analysis

1. The salinity estimates will most likely not be exactly the same.
2. There are many sources of error including, but not limited to:
    a. differences between hydrometers
    b. errors in reading hydrometers
    c. errors in recording hydrometer readings on paper
    d. errors in recording hydrometer readings on board
    e. differences between thermometers
    f. errors in reading thermometers
    g. errors in recording temperature, etc.

It might be helpful to point out to your students that what we see here is two large classes of variation: one group is due to errors within the equipment, the second is due to experimenter errors.

3. Answers depend upon the experimental results.
4. It is possible, but unlikely, that the average is exactly the same as one of the estimates.
5. Answer depends upon the experimental results.
6. Answer depends upon the experimental results, most likely the answer is yes.
7. Conditions that might help account for a range in ocean salinities include differences in rainfall, river outflow, differences in evaporation and differences in rate and degree of mixing.
8. Lowest salinities would be found in areas with high rainfalls and large river outflows. Generally, these conditions obtain in temperate latitudes.
9. Highest salinities would be found in areas with high evaporation rates and low rainfalls and river outflows. Generally, these conditions obtain in equatorial areas.

Part II

Interpretation and Analysis

1. The answers will vary but generally students find the graph method the easier to use.
2. The densities determined using the two techniques will probably not be exactly the same.
3. Answers will depend upon experimental results.
4. Since the charts were the original source of data they should be more accurate. Changing the charts to graphs introduces the possibility of errors in recording, interpretation, etc.
5. The charts should be used when a high degree of certainty is required. They are more cumbersome to use but provide more accurate information. The graph would be used for routine salinity determinations where great precision is not required. If the salinity determination was going to be used to make important management decisions, the charts would be preferred.

KEY WORDS

average

bouyancy

concentration

density - water temperature chart

floatation

hydrometer

parts per thousand (ppt)

range

salinity

salinity corrected density chart

temperature/salinity graph

variation

THE DETERMINATION OF SALINITY - Hydrometer Method

Salts make sea water different from freshwater. The concentrations of the salts affect everything that comes in contact with sea water. Living organisms have to deal with this salinity. To measure the salinity of sea water, oceanographers have developed several techniques. People observed that the saltier the water, the higher something floats in it. Marine scientists use this buoyancy (floatation) information to determine salinity rapidly, with an instrument called a hydrometer. A hydrometer is a weighted glass cylinder with a thin glass tube at the top. The thin tube contains a printed scale (see diagram). The higher the salinity, the higher the tube floats and the larger the number that lines up with the water's surface. Pure water at 4°C is given a density of 1.0000. In this activity you will use a hydrometer to determine the salinity of salt water samples.

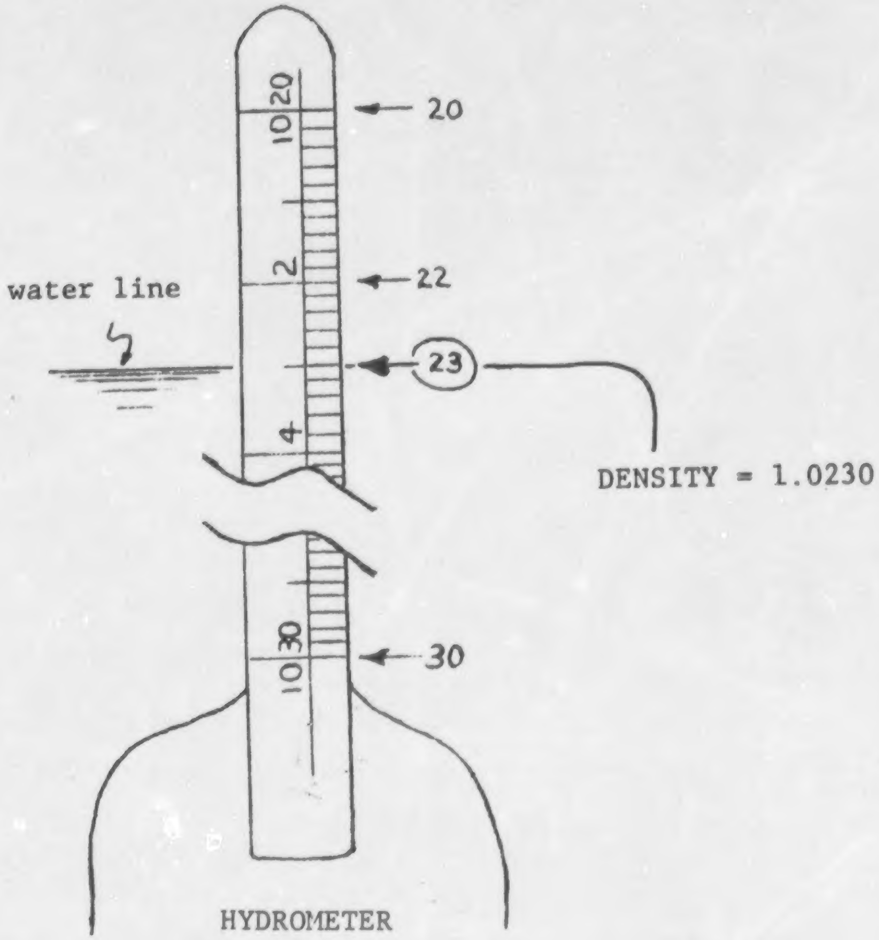
Materials:

Salt water solutions
Thermometer °C
Hydrometer
Density- water temperature chart
Salinity - corrected density chart
Temperature / salinity graph
500 ml graduated cylinder

Procedure:

1. Fill graduated cylinder with 450 ml of your sea water sample.
2. Record water temperature with centigrade thermometer____________.
3. Using the hydrometer, measure the density of your sample. The diagram below will help you read the hydrometer.

   Record the density ______________________________.


1020
20
2
22
water line
23
4
DENSITY = 1.0230
1030
30

HYDROMETER

4. Correct density using density-water temperature chart and record.

Example: density = 1.0230 water temperature = 10°

Find 1.0230 under "Observed density" on the Density-Water Temperature Chart.

Move across to the column marked "10°" under "Temperature of water in jar".

Read: -8. The -8 is the correction factor and is really -.0008.

Subtract:

$$\begin{array}{r} 1.0230 \\ -\ .0008 \\ \hline 1.0222 \end{array}$$

1.0222 = the corrected density reading

Record the corrected density for your sample ____________________.

5. Read salinity from salinity-corrected density chart and record.

Example: Find 1.0222 in the density column.

Read 30.0 in the salinity column to the right of the density 1.0222.

Record the salinity for your sample _________________________o/oo.

6. Save your sea water sample for the activity "Salt II."

7. RECORD YOUR SALINITY ON THE BLACKBOARD as directed by your teacher.

Repeat the above steps for each salt solution provided.

Interpretation and Analysis:

1. Look at the salinity determinations for salt solution number 1. Are all of the salinity estimates for a particular solution the same? ________________.

2. If you see differences in the estimates, list three possible sources of this variation.

   a) ____

   b) ____

   c) ____

Scientist have found that they can obtain more accurate results if they repeat a procedure several times and take an average. The average figure that they obtain has a better chance of being the real (correct) figure than does any of the individual figures.

3. Calculate the average salinity for each of the salt solutions tested. (Hint: This is easy! Take all of the salinity estimates for a given solution and add them together. Divide this sum by the number of estimates. The answer is your average. In other words,

$$\frac{\text{sum of salinity estimates for solution X}}{\text{number of salinity estimates for solution X}} = \begin{array}{l}\text{average salinity}\\ \text{estimate for}\\ \text{solution X.}\end{array}$$

   Please show your work in the space below:

4. Are any of the estimates on the board exactly the same as the calculated average? ______________________________

5. Which solution was the saltiest? ______________________

6. The salinity of sea water ranges from about 25 parts salt/per thousand parts of water (25 ppt) to about 34 parts per thousand. Did either or both solutions fall in this range? If yes, which one(s)? ____

   ____

7. What are two conditions that might help account for a range (from 25 ppt to 34 ppt) in ocean salinities rather than a single uniform salinity?

   a) ____

   b) ____

8. Where would you expect the lowest salinities to be found? Explain.

   ____

   ____

   ____

9. Where would you expect the highest salinities to be found? Explain. ________________________________

   ____

   ____

DENSITY - WATER TEMPERATURE CHART

Observed density	temperature of water																			Ob-served density
	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°	16°	17°	18°	
	Dif.	Dif.	Dif.	Dif.	Dif.	Dif.	Dif.	Dif.	Dif.	Dif.	Dif.	Dif.	Dif.	Dif.	Dif.	Dif.	Dif.	Dif.	Dif.	
1.0000	−3	−4	−5	−6	−6	−6	−6	−6	−6	−5	−5	−4	−3	−2	−1	0	1	2	4	1.0000
1.0010	−4	−5	−6	−6	−6	−6	−6	−6	−6	−5	−5	−4	−3	−2	−1	0	1	3	4	1.0010
1.0020	−4	−5	−6	−6	−7	−7	−6	−6	−6	−6	−5	−4	−3	−2	−1	0	1	2	5	1.0020
1.0030	−5	−6	−6	−7	−7	−7	−7	−6	−6	−6	−5	−4	−3	−2	−1	0	1	2	5	1.0030
1.0040	−5	−6	−7	−7	−7	−7	−7	−7	−6	−6	−5	−4	−3	−2	−1	0	1	2	5	1.0040
1.0050	−6	−7	−7	−7	−8	−7	−7	−7	−7	−6	−5	−5	−4	−3	−1	0	1	2	5	1.0050
1.0060	−6	−7	−8	−8	−8	−8	−8	−7	−7	−6	−6	−5	−4	−3	−1	0	2	3	5	1.0060
1.0070	−7	−7	−8	−8	−8	−8	−8	−7	−7	−6	−6	−5	−4	−3	−1	0	2	3	5	1.0070
1.0080	−7	−8	−8	−8	−9	−8	−8	−8	−7	−7	−6	−5	−4	−3	−1	0	2	3	5	1.0080
1.0090	−8	−8	−9	−9	−9	−9	−8	−8	−7	−7	−6	−5	−4	−3	−1	0	2	3	5	1.0090
1.0100	−8	−9	−9	−9	−9	−9	−9	−8	−8	−7	−6	−5	−4	−3	−1	0	2	3	5	1.0100
1.0110	−9	−9	−10	−10	−10	−9	−9	−8	−8	−7	−6	−5	−4	−3	−1	0	2	3	5	1.0110
1.0120	−9	−10	−10	−10	−10	−10	−9	−9	−8	−7	−6	−5	−4	−3	−1	0	2	3	5	1.0120
1.0130	−10	−10	−10	−10	−10	−10	−9	−9	−8	−7	−6	−5	−4	−3	−2	0	2	3	5	1.0130
1.0140	−10	−11	−11	−11	−11	−10	−10	−9	−8	−7	−7	−6	−4	−3	−2	0	2	3	5	1.0140
1.0150	−11	−11	−11	−11	−11	−10	−10	−9	−9	−8	−7	−6	−4	−3	−2	0	2	3	5	1.0150
1.0160	−11	−11	−12	−11	−11	−11	−10	−10	−9	−8	−7	−6	−5	−3	−2	0	2	4	6	1.0160
1.0170	−12	−12	−12	−12	−12	−11	−11	−10	−9	−8	−7	−6	−5	−3	−2	0	2	4	6	1.0170
1.0180	−12	−12	−12	−13	−12	−11	−11	−10	−9	−8	−7	−6	−5	−3	−2	0	2	4	6	1.0180
1.0190	−13	−13	−13	−13	−13	−12	−11	−10	−9	−8	−7	−6	−5	−3	−2	0	2	4	6	1.0190
1.0200	−13	−13	−13	−13	−13	−12	−11	−11	−10	−9	−7	−6	−5	−3	−2	0	3	4	6	1.0200
1.0210	−14	−14	−14	−13	−13	−12	−12	−11	−10	−9	−8	−6	−5	−3	−2	0	3	4	6	1.0210
1.0220	−14	−14	−14	−14	−13	−13	−12	−11	−10	−9	−8	−6	−5	−3	−2	0	3	4	6	1.0220
1.0230	−15	−15	−14	−14	−14	−13	−12	−11	−10	−9	−8	−6	−5	−3	−2	0	3	4	6	1.0230
1.0240	−15	−15	−15	−14	−14	−13	−13	−12	−10	−9	−8	−7	−5	−3	−2	0	3	4	6	1.0240
1.0250	−16	−15	−15	−15	−14	−13	−13	−13	−11	−9	−8	−7	−5	−4	−2	0	3	4	6	1.0250
1.0260	−16	−16	−16	−15	−15	−14	−13	−12	−11	−10	−8	−7	−5	−4	−2	0	3	4	6	1.0260
1.0270	−17	−16	−16	−15	−15	−14	−13	−12	−11	−10	−8	−7	−5	−4	−2	0	3	4	6	1.0270
1.0280	−17	−17	−16	−16	−15	−14	−13	−12	−11	−10	−9	−7	−5	−4	−2	0	3	4	6	1.0280
1.0290	−18	−17	−17	−16	−16	−15	−14	−13	−12	−10	−9	−7	−5	−4	−3	0	3	4	6	1.0290
1.0300	−18	−18	−17	−17	−16	−15	−14	−13	−12	−10	−9	−7	−6	−4	−3	0	3	4	6	1.0300
1.0310	−19	−18	−18	−17	−16	−15	−14	−13	−12	−10	−9	−7	−6	−4	−3	0	3	4	7	1.0310

SALINITY - CORRECTED DENSITY CHART

[Density at 15° C.—Salinity in parts per 1,000]

Density	Salinity	Density	Salinity	Density	Salinity	Density	Salinity	Density	Salinity	Density	Salinity
0.9991	0.0	1.0046	7.1	1.0101	14.2	1.0156	21.4	1.0211	28.6	1.0266	35.8
.9992	.0	1.0047	7.2	1.0102	14.4	1.0157	21.6	1.0212	28.8	1.0267	35.9
.9993	.1	1.0048	7.3	1.0103	14.5	1.0158	21.7	1.0213	28.9	1.0268	36.0
.9994	.3	1.0049	7.5	1.0104	14.6	1.0159	21.8	1.0214	29.0	1.0269	36.2
.9995	.4	1.0050	7.6	1.0105	14.8	1.0160	22.0	1.0215	29.1	1.0270	36.3
.9996	.5	1.0051	7.7	1.0106	14.9	1.0161	22.1	1.0216	29.3	1.0271	36.4
.9997	.7	1.0052	7.9	1.0107	15.0	1.0162	22.2	1.0217	29.4	1.0272	36.6
.9998	.8	1.0053	8.0	1.0108	15.2	1.0163	22.4	1.0218	29.5	1.0273	36.7
.9999	.9	1.0054	8.1	1.0109	15.3	1.0164	22.5	1.0219	29.7	1.0274	36.8
1.0000	1.1	1.0055	8.2	1.0110	15.4	1.0165	22.6	1.0220	29.8	1.0275	37.0
1.0001	1.2	1.0056	8.4	1.0111	15.6	1.0166	22.7	1.0221	29.9	1.0276	37.1
1.0002	1.3	1.0057	8.5	1.0112	15.7	1.0167	22.9	1.0222	30.0	1.0277	37.2
1.0003	1.4	1.0058	8.6	1.0113	15.8	1.0168	23.0	1.0223	30.2	1.0278	37.3
1.0004	1.6	1.0059	8.8	1.0114	16.0	1.0169	23.1	1.0224	30.3	1.0279	37.5
1.0005	1.7	1.0060	8.9	1.0115	16.1	1.0170	23.3	1.0225	30.4	1.0280	37.6
1.0006	1.8	1.0061	9.0	1.0116	16.2	1.0171	23.4	1.0226	30.6	1.0281	37.7
1.0007	2.0	1.0062	9.2	1.0117	16.3	1.0172	23.5	1.0227	30.7	1.0282	37.9
1.0008	2.1	1.0063	9.3	1.0118	16.5	1.0173	23.7	1.0228	30.8	1.0283	38.0
1.0009	2.2	1.0064	9.4	1.0119	16.6	1.0174	23.8	1.0229	31.0	1.0284	38.1
1.0010	2.4	1.0065	9.6	1.0120	16.7	1.0175	23.9	1.0230	31.1	1.0285	38.2
1.0011	2.5	1.0066	9.7	1.0121	16.9	1.0176	24.0	1.0231	31.2	1.0286	38.4
1.0012	2.6	1.0067	9.8	1.0122	17.0	1.0177	24.2	1.0232	31.4	1.0287	38.5
1.0013	2.8	1.0068	9.9	1.0123	17.1	1.0178	24.3	1.0233	31.5	1.0288	38.6
1.0014	2.9	1.0069	10.1	1.0124	17.3	1.0179	24.4	1.0234	31.6	1.0289	38.8
1.0015	3.0	1.0070	10.2	1.0125	17.4	1.0180	24.6	1.0235	31.8	1.0290	38.9
1.0016	3.2	1.0071	10.3	1.0126	17.5	1.0181	24.7	1.0236	31.9	1.0291	39.0
1.0017	3.3	1.0072	10.5	1.0127	17.6	1.0182	24.8	1.0237	32.0	1.0292	39.2
1.0018	3.4	1.0073	10.6	1.0128	17.8	1.0183	25.0	1.0238	32.1	1.0293	39.3
1.0019	3.5	1.0074	10.7	1.0129	17.9	1.0184	25.1	1.0239	32.3	1.0294	39.4
1.0020	3.7	1.0075	10.8	1.0130	18.0	1.0185	25.2	1.0240	32.4	1.0295	39.6
1.0021	3.8	1.0076	11.0	1.0131	18.2	1.0186	25.4	1.0241	32.5	1.0296	39.7
1.0022	3.9	1.0077	11.1	1.0132	18.3	1.0187	25.5	1.0242	32.7	1.0297	39.8
1.0023	4.1	1.0078	11.2	1.0133	18.4	1.0188	25.6	1.0243	32.8	1.0298	39.9
1.0024	4.2	1.0079	11.4	1.0134	18.6	1.0189	25.8	1.0244	32.9	1.0299	40.1
1.0025	4.3	1.0080	11.5	1.0135	18.7	1.0190	25.9	1.0245	33.0	1.0300	40.2
1.0026	4.5	1.0081	11.6	1.0136	18.8	1.0191	26.0	1.0246	33.2	1.0301	40.3
1.0027	4.6	1.0082	11.8	1.0137	19.0	1.0192	26.1	1.0247	33.3	1.0302	40.4
1.0028	4.7	1.0083	11.9	1.0138	19.1	1.0193	26.3	1.0248	33.4	1.0303	40.6
1.0029	4.8	1.0084	12.0	1.0139	19.2	1.0194	26.4	1.0249	33.6	1.0304	40.7
1.0030	5.0	1.0085	12.2	1.0140	19.4	1.0195	26.5	1.0250	33.7	1.0305	40.8
1.0031	5.1	1.0086	12.3	1.0141	19.5	1.0196	26.7	1.0251	33.8	1.0306	41.0
1.0032	5.2	1.0087	12.4	1.0142	19.6	1.0197	26.8	1.0252	34.0	1.0307	41.1
1.0033	5.4	1.0088	12.6	1.0143	19.7	1.0198	26.9	1.0253	34.1	1.0308	41.2
1.0034	5.5	1.0089	12.7	1.0144	19.9	1.0199	27.1	1.0254	34.2	1.0309	41.4
1.0035	5.6	1.0090	12.8	1.0145	20.0	1.0200	27.2	1.0255	34.4	1.0310	41.5
1.0036	5.8	1.0091	12.9	1.0146	20.1	1.0201	27.3	1.0256	34.5	1.0311	41.6
1.0037	5.9	1.0092	13.1	1.0147	20.3	1.0202	27.4	1.0257	34.6	1.0312	41.8
1.0038	6.0	1.0093	13.2	1.0148	20.4	1.0203	27.6	1.0258	34.7	1.0313	41.9
1.0039	6.2	1.0094	13.3	1.0149	20.5	1.0204	27.7	1.0259	34.9	1.0314	42.0
1.0040	6.3	1.0095	13.5	1.0150	20.6	1.0205	27.8	1.0260	35.0	1.0315	42.1
1.0041	6.4	1.0096	13.6	1.0151	20.8	1.0206	28.0	1.0261	35.1	1.0316	42.3
1.0042	6.6	1.0097	13.7	1.0152	20.9	1.0207	28.1	1.0262	35.3	1.0317	42.4
1.0043	6.7	1.0098	13.9	1.0153	21.0	1.0208	28.2	1.0263	35.4	1.0318	42.5
1.0044	6.8	1.0099	14.0	1.0154	21.2	1.0209	28.4	1.0264	35.5	1.0319	42.7
1.0045	7.0	1.0100	14.1	1.0155	21.3	1.0210	28.5	1.0265	35.6	1.0320	42.8

Part II

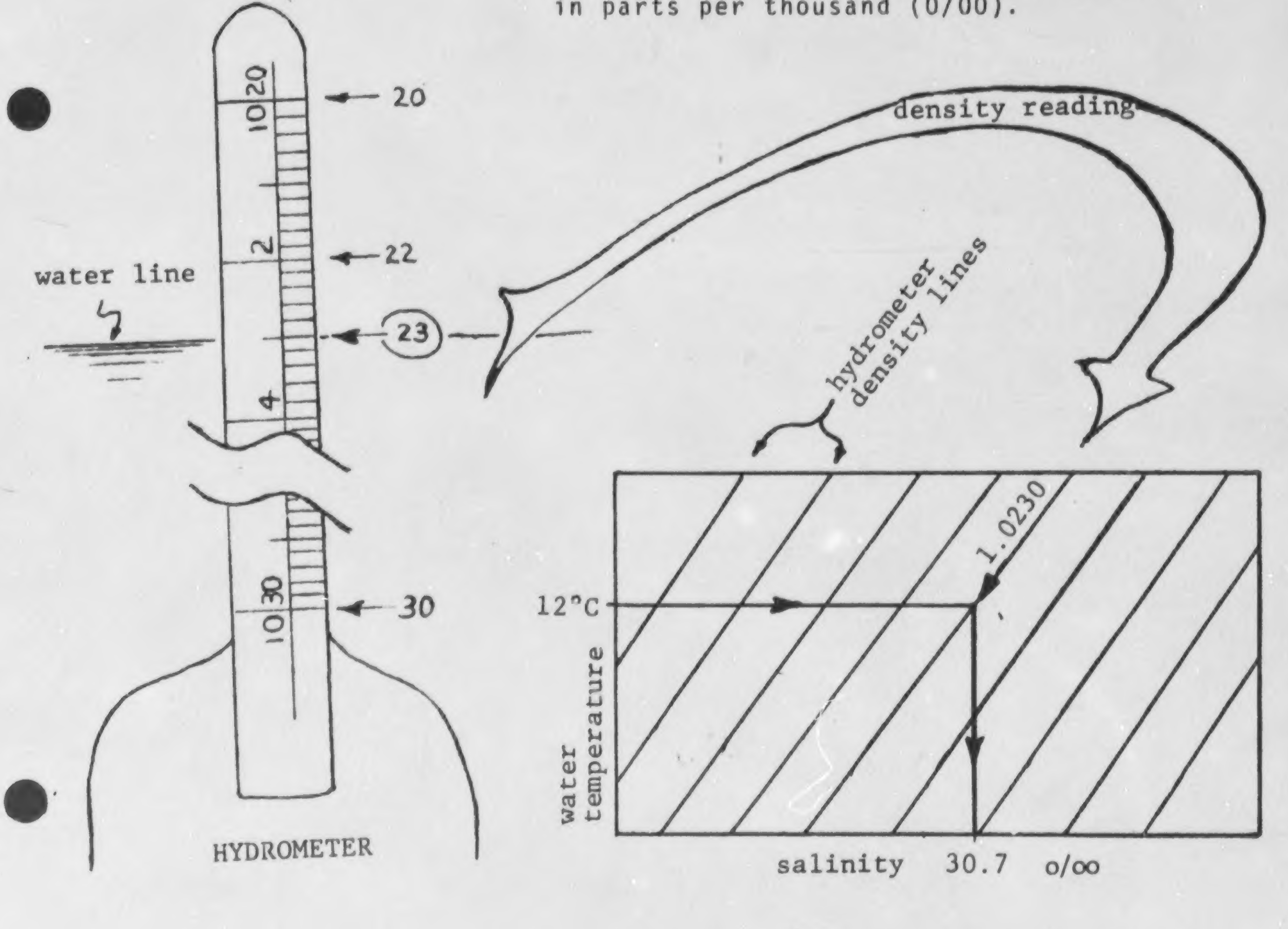
Using the density-water temperature chart and the salinity-corrected chart can be tedious. To make things a bit quicker scientists have developed a hydrometer-temperature graph which corrects for differences in temperature. Using this graph you will again determine the salinities that correspond to the hydrometer densities you discovered.

PROCEDURE

1. Use the hydrometer-temperature graph to read the salinity.

EXAMPLE: To Find Salinity:

a. Find correct water temperature on graph.
b. Follow temperature line over until you meet correct hydrometer density line.
c. From this point drop straight down and read off correct salinity of your sample in parts per thousand (0/00).


10 20
20
2
22
water line
23
4
10 30
30
HYDROMETER
density reading
hydrometer density lines
1.0230
12°C
water temperature
salinity 30.7 o/oo

Record your salinity:

Salinity for sample # ______________ is ______________________ o/oo

Interpretation And Analysis

1. Which method of determining salinity from density data did you find easier? Why?

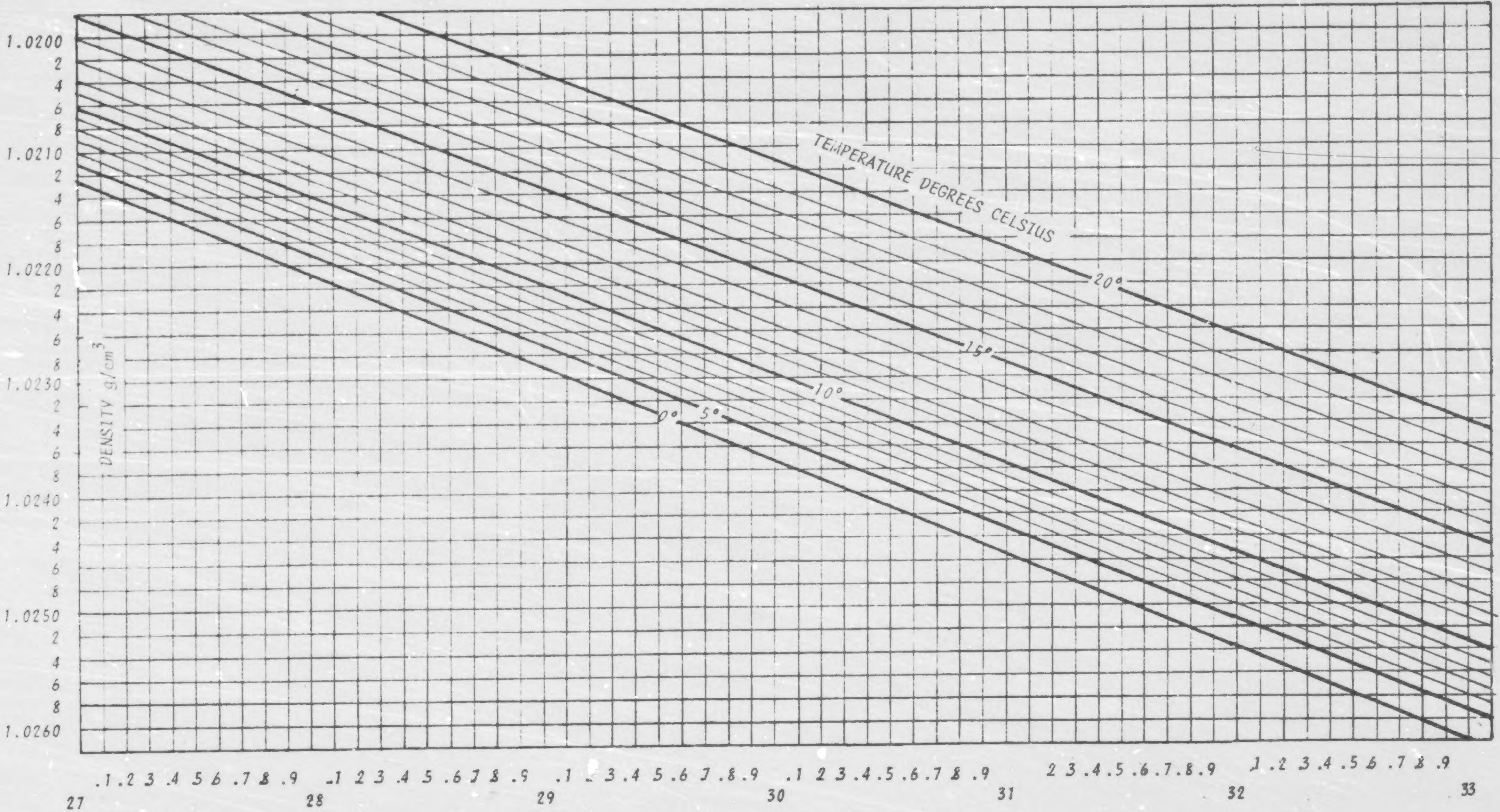
2. Were the densities you determined using the charts exactly the same as those that you determined using the graph?

3. By what percentage does the graph salinity determination for the first sample differ from the chart salinity determination?

(HINT: $\% \text{ difference} = \frac{(\text{chart salinity}) - (\text{graph salinity})}{\text{chart salinity}} \times 100$)

Please show your work in the space below:

4. The graph was constructed from the charts. Which do you think is more accurate? Why?


TEMPERATURE DEGREES CELSIUS
20°
15°
10°
5°
0°
DENSITY g/cm^3
1.0200
2
4
6
8
1.0210
2
4
6
8
1.0220
2
4
6
8
1.0230
2
4
6
8
1.0240
2
4
6
8
1.0250
2
4
6
8
1.0260
.1 .2 .3 .4 .5 .6 .7 .8 .9
27
28
29
30
31
32
33
SALINITY 0/00

276

276 A

TEACHER BACKGROUND Salt II

"Salt II" is a quantitative look at sea water designed to complement "Hydrometer Salinity". The students will determine just how much salt is in a given sample of sea water. This investigation provides an opportunity for careful measurement.

A balance and weights or a scale capable of weighing 50 grams accurately is required. If you do not have one in your class, plan to obtain one from another teacher. The same goes for the graduated cylinders. Several of each will make the lab go faster. If you only have one or two, you can run this activity simultaneously with "Hydrometer Salinity". In this way, you can avoid long lines for the equipment. It is also possible to do this investigation as a demonstration. Demonstration is less preferable than student inquiry, but is better than skipping the activity. If you do choose the demonstration route, demonstrate without providing all of the answers. Provide the data and let the student work out the solutions to the questions you pose.

Duplicate the activity pages. One set is recommended per student. Note the "CAUTION" in the student text. Do not let the beakers boil dry on the hot plate. They will crack even though they are heat-resistant pyrex glass. Have students reduce temperature at this point. It is also helpful to slightly tilt the beaker to reduce the spattering of salt. This portion of the procedure requires careful technique since all of the moisture must be removed from the salt while keeping the beaker whole.

KEY

1. The answer depends upon the experimental results but it is very unlikely that the two salinity determinations will be exactly the same.

2. There are many possible sources of error: moisture in the salt, salt spattering, incorrect weighings, incorrect hydrometer readings, incorrect use of charts, etc. This is a good time to talk about errors in experiments and how to minimize them.

3. The answers will depend upon the experiences your students had in performing the experiments. One improvement might be to use an oven to dry the sample thoroughly.

4. This question stresses the value of averaging repeated observations. Repetition shows obvious errors and gives results more likely to be correct.

5. The salt concentration of the remaining solution increases.

6. The salinity of the pools increases as the pools dry. This increased salinity can have rather dramatic effects on an organism since the high salt concentrations tend to draw water out of the cells resulting in dehydration. This is a good chance to preview forthcoming discussions on the myriad of adaptations that marine organisms have evolved to deal with salinity changes.

KEY WORDS

balance
beaker
concentration
determination
evaporate
graduated cylinder
grams
hydrometer
residue
salinity
solution
techniques

SALT II

In this investigation you will use 50 ml of the sea water you used in your hydrometer determination of salinity. You will evaporate the water and calculate the salinity and percent of salt of the sample. You can then compare your results with those you obtained using the hydrometer.

Materials:

- beaker (150 or 250 ml)
- thermometer
- sea water
- beaker tongs
- tray - heat resistant
- balance and weights
- graduated cylinder
- hot plate
- stopwatch or timer
- saftey glasses or goggles

Procedure:

1. Use the balance to weigh the empty beaker. Record the weight of the empty beaker. _______________grams.
2. Measure 50 ml sea water using a graduated cylinder. Then pour into beaker.
3. Determine the weight of the beaker plus the sea water. Record the combined weight. _______________grams.
4. To determine weight of water, subtract the empty beaker weight (#1) from the weight of the beaker plus 50 ml of sea water (#3).

beaker + water (#3) _______________grams

subtract empty beaker (#1) _______________grams

weight of water = _______________grams

5. Place beaker on hot plate and evaporate all the water.

NOTE: Record the time and temperature at which the sea water. begins to boil. CAUTION: Don't let the beaker boil completely dry as beaker will crack. You do, however, want to evaporate all of the water.

As the water is being evaporated, record the temperature every 2 minutes.

Remove beaker from hot plate and place on tray.

Starting Temp. ____________ 10 min. ______________ 20 min. __________

2 min. ________________ 12 min. ______________ 22 min. __________

4 min. ________________ 14 min. ______________ 24 min. __________

6 min. ________________ 16 min. ______________

8 min. ________________ 18 min. ______________

Boiling Temperature ______________________________

6. Weigh beaker with dry salt residue left in it. Record the weight in grams. ______________ grams.

7. To find the weight of salt, subtract the weight of the empty beaker (#1) from the weight of the beaker plus the salt residue (#6).

beaker and salt residue (#6) ______________ grams

subtract empty beaker (#1) ______________ grams

Weight of Salt = ______________ grams.

8. The percent of salt is found by dividing the weight of the residue by the weight of the sea water used.

weight of salt (#7) _________ grams
________________________________ = _________ grams x 100 = _________ %.
weight of sea water (#4) _________ grams

9. The salinity of ocean water is commonly expressed by so many parts of salt material per 1000 parts of water. We use the symbol o/oo to express parts per thousand. To determine parts per thousand take the per cent of salt and multiply by 10.

Per cent of salt (#8) _________ x 10 = _________ o/oo

Analysis and Interpretation:

1. Is the salinity you determined by evaporation exactly the same as that which you determined using the hydrometer and the correction charts?

2. If your salinities were different, what are two possible sources of the difference?

3. What is one way in which you could improve the techniques used in salinity determination by evaporation?

4. The original determinations of the salinity of sea water were made by evaporation. The investigators performed the experiment several times on samples of sea water from the same area. Why did they repeat the experiment rather than accept the first results without question?

5. As you evaporate the water, what happens to the concentration of the salt in the remaining solution?

6. Animals and plants that live in the tidal zone, where the water in the tide pools evaporates, face changes in salinity. How does the salinity change as the pools dry? How might this change affect the organisms?

TEACHER BACKGROUND - The Effect of Salinity on Living Tissue

Living cells are comprised of various solids suspended in a salt solution. In a very real sense we all carry our personal oceans with us where ever we go. Aquatic animals must deal with the movement of fresh water into or out of their tissues in order to maintain a constant internal salt concentration. "The Effect of Salinity on Living Tissue" looks at the movement of water into and out of the living cells of a potato. Osmosis may also be demonstrated using live sea urchin eggs; hens eggs with the shells dissolved away in dilute hydrochloric acid; or red blood cells.

Duplicate the activity pages. One set is recommended per student. This activity may be performed in groups of three or four. This activity requires potato cores which can be made by inserting a cork borer or other cylinder with a diameter of about ¼ of an inch into a potato to a depth of one inch. With a little practice, uniform cores can be made. The change in mass is measured either by using a balance or a graduated cylinder. The water filled graduated cylinder is read before and after soaking the core to give the change in displacement of the core. The balance gives the change in weight by measuring weight before and after immersion. The graduated cylinder has the attraction of putting a wet core into a wet cylinder. The problems arising from diffusion into and out of the potato core while in the water in the graduated cylinder can be minimized if the measurements are done quickly. During the half hour period of immersion, you can have your students work on another project, for example the results from "Salt II".

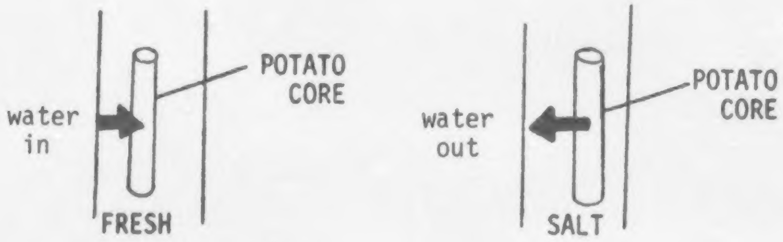
The "One Step Further....." pages provide additional practice with the concept of osmosis. The activity pages may be used as an in-class assignment, as homework, or as a quiz for evaluation of the material covered in the activity "The Effect of Salinity on Living Tissue". The approach you adopt will depend upon your particular situation. Regardless of the approach, duplicate the activity pages. This activity lends itself best to individual completion, although it is possible to have small groups work together on the questions. Allow sufficient time to discuss the questions and to provide the correct answers upon completion of the activity.

KEY

3. The descriptions will vary according to the cores used but should include all of the items listed with the exception of either "weight" or "volume of water displaced". The item omitted will depend upon the technique you use to measure the mass change.
7. See number 3 above.

Results and Interpretation

1. Answers depend upon the experimental results obtained.
2. Answers depend upon the experimental results.
3. The change in weight or volume most likely occurred because of the movement of water into or out of the potato core.
4.



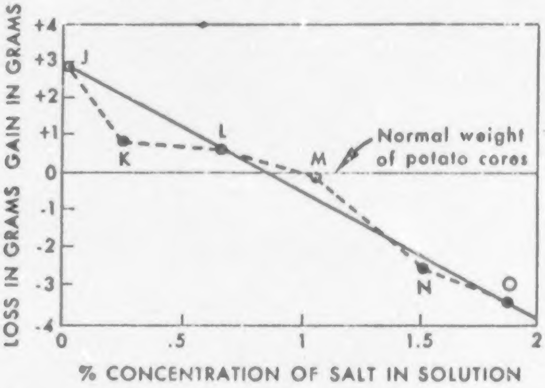
5. a. Freshwater from the tank will move into the sea cucumber's cells in an effort to dilute the salt concentration of the cells. As a result of this movement the cells will swell and the sea cucumber will gain weight.

   b. In a salt solution twice as concentrated as that of sea water, the water molecules within the cells of the sea cucumber will move out of the cells in an attempt to dilute the concentration of the salt solution in the tank. The sea cucumber will lose weight as the tissues decrease in size due to the water loss. The movement of water in osmosis tends to make the concentrations equal on both sides of the cell membrane to what ever degree possible.

6. In water saltier than their tissue fluids, fish have to deal with dehydration. There is a tendency for water to move out of the cells and into the surrounding solution. The fish shrinks and loses weight. Fish have evolved many ways to deal with the problem of water loss. Some fish, for instance sharks, drink salt water. They are able to "distill" the water and excrete the salt through special structures. Regulation of the salt content of their tissues is a constant process for aquatic creatures.
7. In water less salty than their tissue fluids, fish have to deal with hydration. There is a tendency for water to move into the cells from the surrounding solution. The cells swell and the fish gains weight. Fish in fresh water face this problem constantly. Most of them deal with the problem by excreting the excess water through their well developed kidneys.

One Step Further......

The correct answers are those underlined below.



1. Cores J, K, and L are above the normal weight here because

   A. there was a flow of water out of each core.

   B. salt entered the cores and made them heavier.

   C. water entered the cores and increased their weights.

   D. all of these cores weighed more than three grams.

2. The best explanation for the dots not appearing on the normal weight line is that

   [✓ A.] there has been a movement of water.

   B. there has been a change in the core's volume.

   C. there has been a movement of salt.

   D. a normal variation in experimental measurement occurred.

3. If there were no change in the weight of a potato core after immersion in salt solution it most likely means

   A. water could not enter the core.

   B. water could not leave the core.

   [✓ C.] salt concentration inside the core was equal to the concentration outside.

   D. the membrane was not permeable to salt.

4. A potato core placed in a 5% salt solution would most likely

   A. gain more weight than core J.

   [✓ B.] lose more weight than core O.

   C. behave like core M.

   D. behave in a manner we cannot predict with the information we now have.

5. Potato core M had a salt concentration of:

   A. 0

   [✓ B.] 1.1

   C. 1.8

   D. the same as core N.

6. The dots J, K, L, M, N, and O represent

   A. variables.

   B. assumptions.

   C. hypotheses.

   [✓ D.] data.

7. The best reason for drawing a straight line between but not connecting each dot is that

   A. it assumes experimental error.

   B. averaging results makes generalizations more meaningful.

   C. the indivudual results are often wrong.

   D. the dotted line is a fact, while each dot is an assumption.

KEY WORDS

adapt

anadromous

assumptions

averaging

balance

cell

concentration

data

displaced

generalizations

graduated cylinder

hypotheses

membrane

percentage change

osmosis

permeable

potato core

salinity

specialized

tissue

variables

volume

THE EFFECT OF SALINITY ON LIVING TISSUE

Most marine plants and animals have to deal with small changes in the salinity of the waters in which they live. A few marine fish are anadromous, they spend part of their lives in freshwater and part in salt water. Salmon for instance, are born in freshwater streams, migrate to the sea where they mature, and return to the freshwater stream where they hatched to reproduce and die. How do these changes in salinity affect the plants and animals? How do plants and animals adapt to these changes? Perhaps we can learn something about the process by observing the effect of different salinities on living tissue.

Materials:

test tubes (two)
test tube rack
potato cores (two)
salt water
fresh water
centimeter ruler
balance or graduated cylinder
labels

Procedure:

1. Obtain two empty test tubes. Label one "salt water" and the other "fresh water".
2. Fill each tube about three quarters full with the correct solution. Place the tubes in a test tube rack.
3. Obtain two potato cores. Describe the two cores:

Potato core 1 (salt water)	Potato core 2 (fresh water)
color	
weight	

volume of water displaced

length

width

4. Place potato core 1 in the tube of salt water.
5. Place potato core 2 in the tube of freshwater.
6. Place the two tubes aside and let them stand for at least 1/2 hour.
7. When the time has elapsed, remove the potato cores and describe:

Potato core 1 (salt water)	Potato core 2 (fresh water)
color	
weight	
volume of water displaced	
length	
width	

Analysis and Interpretation:

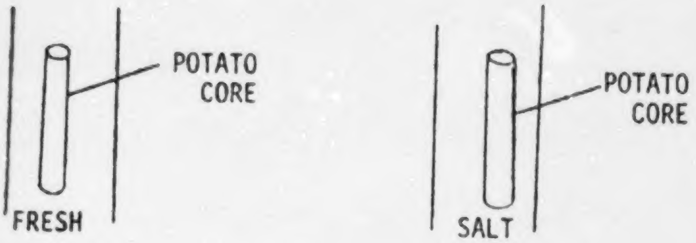
1. Calculate the percentage change in weight or the percentage change in volume of water displaced by each potato core. This is easy, here's how:

$$\frac{\text{Weight of core before soaking}}{\text{Weight of core after soaking}} \times 100 = \text{percentage change}$$

2. Which potato core had the greatest change?

3. What most likely happened to cause any change in weight or volume seen?

4. Use the diagram below to show whether the water moved into or out of the potato.



5. Danny Devious wants to change the surroundings of his pet sea cucumber. Danny has put his pet into a tank of fresh water. What is going to happen to the living tissue of the sea cucumber? (b) Danny notices something awry. "Aha! I forgot the salt". Quickly he adds a pound of table salt. The resulting salt solution is about twice the concentration of sea water. Assume that Danny's pet was still living, what is now going to happen to the living tissue of the sea cucumber?

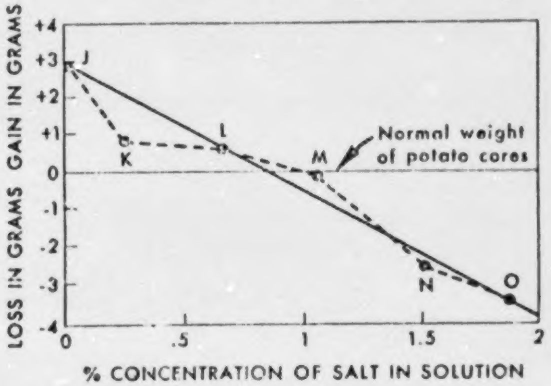
The movement of water into and out of living cells is called osmosis. Plants and animals living in aquatic environments have developed many specialized structures and behaviors to help them deal with the inflow and outflow of water.

6. What is the problem fish have to deal with in water saltier than their tissue fluids?

7. What is the problem fish have to deal with in water less salty than their tissue fluids?

ONE STEP FURTHER.........

In order to further study the effect of salt on living tissue, a group of students performed the following experiment. They placed potato cores of uniform size in a series of different salt solutions from 0% to 2%. After waiting a half hour, the loss or gain of weight in grams was measured. Their results are shown graphically below. Use this information to answer the following questions.



1. Cores J, K, and L are above the normal weight here because
   A. there was a flow of water out of each core.
   B. salt entered the cores and made them heavier.
   C. water entered the cores and increased their weights.
   D. all of these cores weighed more than three grams.

2. The best explanation for the dots not appearing on the normal weight line is that
   A. there has been a movement of water.
   B. there has been a change in the core's volume.
   C. there has been a movement of salt.
   D. a normal variation in experimental measurement occurred.

3. If there were no change in the weight of a potato core after immersion in salt solution it most likely means
   A. water could not enter the core.
   B. water could not leave the core.
   C. salt concentration inside the core was equal to the concentration outside.
   D. the membrane was not permeable to salt.

4. A potato core placed in a 5% salt solution would most likely
   - A. gain more weight than core J.
   - B. lose more weight than core O.
   - C. behave like core M.
   - D. behave in a manner we cannot predict with the information we now have.

5. Potato core M had a salt concentration of:
   - A. 0
   - B. 1.1
   - C. 1.8
   - D. the same as core N.

6. The dots J, K, L, M, N, and O represent
   - A. variables.
   - B. assumptions.
   - C. hypotheses.
   - D. data.

7. The best reason for drawing a straight line between but not connecting each dot is that
   - A. it assumes experimental error.
   - B. averaging results makes generalizations more meaningful.
   - C. the individual results are often wrong.
   - D. the dotted line is a fact, while each dot is an assumption.

TEACHER BACKGROUND - The Determination of Salinity - Titration Method

Most tests used to determine the concentrations of dissolved substances in sea water fall into one of two distinct catagories: colorimetric tests or titrametric tests. Both of these catagories depend upon color change as a means for determining the concentration of an unknown substance in the sample which is being analyzed. In colorimetric tests, the intensity of the color which develops is related to the concentration of the unknown substance in the water sample. In titrametric tests such as the following test for salinity, a chemical reagent is slowly added to an exact volume of a water sample which has been previously treated in some specified manner. At some point when the reagent is being added, there will be a distinct color change called the "end point". The volume of the reagent (titrant) which must be added to bring about this color change is directly related to the concentration of the substance in the water sample being tested.

The accuracy of titrametic tests depends upon several factors. The strengths and volumes of solutions used must be carefully measured. Glassware must be clean and the graduations must be accurate to obtain good results. Although your students may not appreciate the fine points of titration, they can easily detect the color change, measure the titrant used and correctly determine the salinity concentration. Reasonable care in technique will assure results that will provide ample material for discussion and consideration.

Duplicate the text and activity pages. One set is recommended per student. The students should be made thoroughly aware of the safety problems to be encountered in any exercise wherein chemicals are employed. Silver nitrate stains clothing, skin and other items. Spillage must be cleaned, rinsed and dried. Tall burets filled with titrants topple easily. The resulting mess is often wide-spread.

Overflows and spillages over the top of the buret are at eye-level or above. Eyes must be protected at all times. Be sure your students WEAR EYE PROTECTION!

Once silver nitrate is prepared, deterioration of the solution begins with exposure to light, evaporation and air borne contamination. Fresh solutions yield the best results. As the titration procedes, the clumps of silver chloride formed should be reduced by periodic, vigorous agitation. The addition of 2 or 3 small plastic beads to the reacting vessel is helpful in breaking clumps.

Although the pH determination of the sample is not made a part of this exercise, good results require a pH of 7-10. Adjust samples of pH below 7 with 0.1N NaOH.

The student must be able to read the meniscus in order to correctly do this exercise.

Preparation of the $AgNO_3$ titrant:

Measure 49 grams of crystalline $AgNO_3$. Dissolve the crystals in approximately .5L of ion-free water (distilled). Be sure all crystals have completely dissolved. Fill with more ion-free H_2O to the one liter mark.

This solution must be stored in a dark brown bottle. If several bottles are used, the contamination of one will be a lesser problem. Each buret filling requires about 50 ml of $AgNO_3$ solution. One liter will fill 20 burets (with care).

Preparation of the K_2CrO_3 solution. One liter will fill 20 burets (with care).

Preparation of the K_2CrO_4 indicator:

Add 3.5 grams of K_2CrO_4 yellow crystals to 100 ml of distilled H_2O.

Encourage careful and accurate laboratory techniques. Circulate around the room as the titrations are performed looking for possible dangers and problems with procedure. Plan to spend some time after completion of the activities in the discussion of the results and procedures.

KEY

1. Answer depends upon experimental results.
2. The second sample provides a check. If the results are widely different, the experimenter is alerted to look for a problem.
3. The best estimate will most likely be the average.
4. The best estimate is the average since it tends to minimize any errosion technique.
5. If a volume of sea water other than 10 ml is used, the correction used is:

$$\frac{10}{\text{volume of sea water}} \times \text{volume of silver nitrate}$$

6. In theory, it would be possible to introduce a known number of chloride ions (either by weight of solid NaCl or by volume of a known concentration) and retitrate. In practice, its best to throw out the sample and begin again.
7. The freshwater outflow can be traced by measuring the salinity gradient from the mouth of the river to the point where you reach the salinity of the open ocean.
8. One way to determine salinity tolerance is to place the organism in a container and gradually change the salinity while monitoring the effects upon the animal or plant. You might also get an idea of the tolerances by observing where the organism is found although salinity is not the only factor governing where an animal can live.
9. The salinity preference of an organism helps determine where it can live. If we find an organism living in an area, we can assume that the area has a salinity within the tolerance limits of that organism. Organisms are "living salionmeters" in the sense that the areas in which they are found must have salinities within their

tolerance range. The organism provides us with the information necessary to determine the approximate salinity of the area in which it is living.

10. One way to deal with changes in salinity is to leave. This is not an option available to plants. Organisms can adapt by changing their "internal salinity" as the salinity of the external environment changes. Other mechanisms are also possible. Some organisms seal themselves in an impermeable shell until the original salinity returns. Use this question as a springboard for discussion of the effects of salinity on living things.

KEY WORDS

agitate
aliquot
average
buret
chloride ion
concentration
density
dissolve
elements
end point
estimate
estuaries
freshwater
halocline
idiosyncrasies
indicator
internal ratio
leaching
meniscus
minerals
parts per thousand (o/00)
precipitate
reagent
salinity

salinity preference
silver nitrate
stopcock
titrant
titration
tolerance
volume

The student titrations and calculations are a modified version of standard procedures used to determine the salinity of water samples. For those who wish to pursue the subject in more detail, the theory and background of the standard technique is available by consulting:

Strickland, J.D.H. and T.R. Parsons, 1972,
A practical Handbook of Seawater Analysis,
Fisheries Research Board of Canada: Bulletin 167,
Ottawa.

THE DETERMINATION OF SALINITY - Titration Method

Salinity is an important factor in the life of the sea. Sea water surrounds the plants and animals that live in the sea. The concentration of the salts in this sea water determines whether the organism has to safeguard against dessication (excessive loss of water) or hydration excessive inflow of water). In this activity you will determine the salinity of sea water.

To determine the salinity of your sample of sea water you will use a titration technique. In a titration test, a chemical reagent (a substance used to measure another substance) is slowly added to an exact volume of a water sample which has been previously treated. At some point when the reagent is being added, there will be a distinct color change called the "end point". The volume of the reagent (called the titrant) which must be added to bring about this color change is directly related to the concentration of the substance in the water sample being tested.

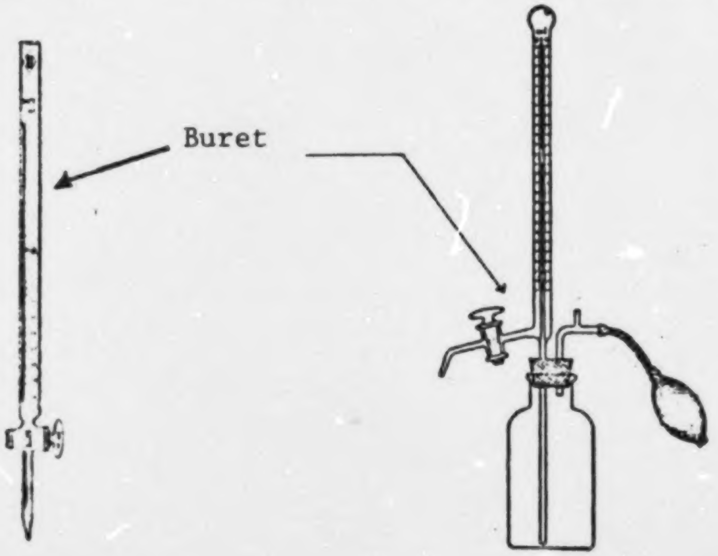
This activity requires care. You will be using silver nitrate ($AgNO_3$) in the technique. Although silver nitrate is colorless, it will stain desk tops, clothes and skin. Begin by wiping the work area with a wet paper towel. Dry the area. Wear safety glasses for eye protection. Wipe up any spills as they occur.

Materials:

50 ml buret
125 ml Erlenmeyer
A_gNO_3 titrant solution
K_2CrO_3 indicator solution
Distilled H_2O
50 ml beakers (2)
10 ml pipet
safety glasses or goggles

Procedure:

1. Arrange the work area for maximum usability and minimum clutter. Once titration begins, nothing should interfere.
2. Fill buret with distilled H_2O. Drain buret in short spurts. Try to adjust the stopcock so as to deliver drops and a single drop on demand. Now is the time to learn the idiosyncrasies of the stopcock. Be sure it operates without leaking.



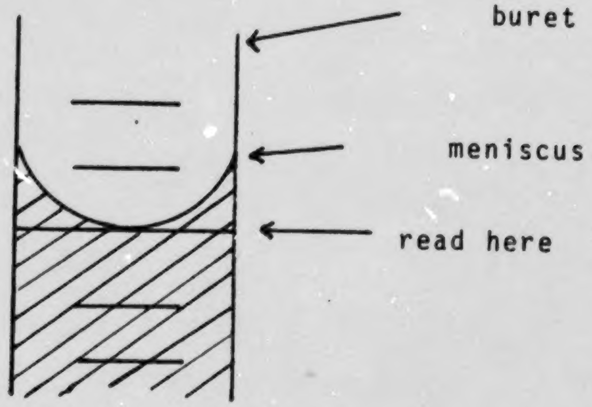
The instructor should be informed about an inoperative buret assembly immediately.

3. Pipet 10 ml of sea water into the 125 ml flask. Add about 10 ml of distilled H_2O. Add 2 or 3 plastic beads. Label this "Sample Number 1".

Erlenmeyer
Flask

Pipet

4. Put 4-6 drops of K_2CrO_4 into the flask. This is the indicator The indicator will change color at the "endpoint".
5. Fill a 50 ml beaker with $AgNO_3$.
6. Pour about 5 ml of $AgNO_3$ into the buret. Drain into the other 50 ml beaker. Pour this into a waste jar.
7. Partially fill the buret with $AgNO_3$. Turn stopcock to fill the buret exactly to "0" or exactly to "50" (the top reading). This is time consuming.
8. On your data sheet RECORD the reading at the start (read meniscus; see diagram below). The buret either has "50" or "0" or both as the top graduation. In either case record the starting and ending graduations. Subtract the smaller from the larger to find the volume of $AgNO_3$ used in milliliters. Most burets can be read to the tenth of c milliliter.



HOW TO READ THE MENISCUS

9. Slowly let the silver nitrate solution drain from the buret while constantly swirling the flask.
10. Agitate the flask. DO NOT LOSE ANY LIQUID. To make sure, use a stopper.
11. Repeat steps 9 and 10 until the first pink-orange color appears.
12. Agitate well. The clumps of precipitate must be reduced to very small particles. The flask contents should return to the original color.
13. Add $AgNO_3$ drop by drop while agitating the flask contents sufficiently to keep the precipitate particles small. When the pink color reappears, "catch" the hanging drop. Stopper the flask. Shake vigorously. If the pink color remains, this is the end point. Otherwise, repeat Step 13. RECORD the buret reading.
14. Once the end point is reached calculate the volume of $AgNO_3$ used.

    (Larger reading) - (smaller reading) = volume of $AgNO_3$ used

    RECORD the volume on your data sheet.

    This volume is the chlorosity of the water sample.

15. Use the conversion table found on the next page to find the salinity.

    How to use the table:

    1. The column marked Cl/liter $_{(20)}$ shows different chlorosities. Read down the column until you find the number that matches your experimental results.

    2. Next, read the number on the same line, but one column to the right under the heading S o/oo. This figure is the salinity corresponding to the chlorosity you determined experimentally.

       An example is blocked in for you. If you determined a chlorosity of 19.55, then your salinity is 34.47 parts per thousand.

    3. RECORD your salinity for sample number 1.

    Note: This table assumes a temperature of 20°C. If your determination was performed at a different temperature, the salinities you read on the chart will not be completely accurate. For this activity, assume your working temperature was 20°C.

16. Repeat steps 1 to 15 on a second sample of water from the same location. This is sample number 2.

17. Complete your data sheet. RECORD the difference, the average, and the percent error.

18. Clean your glassware and your work area.

Analysis And Interpretation:

1. List your results on the chalkboard with all other students who titrated the same sea water sample. What is the average salinity of all of these titrations?

2. Why is it a good idea to make two titrations of the same sample?

CONVERSION OF CHLOROSITY TO SALINITY (20°C)

Cl/liter$_{(20)}$	*S*‰	*Cl*/liter$_{(20)}$	*S*‰	*Cl*/liter$_{(20)}$	*S*‰	*Cl*/liter$_{(20)}$	*S*‰	*Cl*/liter$_{(20)}$	*S*‰
18.00	31.80	18.50	32.67	19.00	33.53	19.50	34.39	20.00	35.25
.01	.82	.51	.68	.01	.54	.51	.40	.01	.27
.02	.84	.52	.70	.02	.56	.52	.42	.02	.28
.03	.86	.53	.72	.03	.58	.53	.44	.03	.30
.04	.87	.54	.73	.04	.60	.54	.46	.04	.32
.05	.89	.55	.75	.05	.61	.55	.47	.05	.34
.06	.91	.56	.77	.06	.63	.56	.49	.06	.35
.07	.92	.57	.79	.07	.65	.57	.51	.07	37
.08	.94	.58	.80	.08	.67	.58	.52	.08	.39
.09	.96	.59	.82	.09	.68	.59	.54	.09	.40
18.10	31.98	18.60	32.84	19.10	33.70	19.60	34.56	20.10	35.42
.11	31.99	.61	.86	.11	.72	.61	.58	.11	.44
.12	32.01	.62	.87	.12	.73	.62	.59	.12	.46
.13	.03	.63	.89	.13	.75	.63	.61	.13	.47
.14	.05	.64	.91	.14	.77	.64	.63	.14	.50
.15	.06	.65	.92	.15	.79	.65	.64	.15	.51
.16	.08	.66	.94	.16	.80	.66	.66	.16	.52
.17	.10	.67	.96	.17	.82	.67	.68	.17	.54
.18	.11	.68	.98	.18	.84	.68	.70	.18	.56
.19	.13	.69	32.99	.19	.85	.69	.71	.19	.58
18.20	32.15	18.70	33.01	19.20	33.87	19.70	34.73	20.20	35.59
.21	.17	.71	.03	.21	.89	.71	.75	.21	.61
.22	.18	.72	.05	.22	.91	.72	.77	.22	.63
.23	.20	.73	.06	.23	.92	.73	.78	.23	.64
.24	.22	.74	.08	.24	.94	.74	.80	.24	.66
.25	.23	.75	.10	.25	.96	.75	.82	.25	.68
.26	.25	.76	.11	.26	.97	.76	.83	.26	.70
.27	.27	.77	.13	.27	33.99	.77	.85	.27	.71
.28	.29	.78	.15	.28	34.01	.78	.87	.28	.73
.29	.30	.79	.17	.29	.03	.79	.89	.29	.74
18.30	32.32	18.80	33.18	19.30	34.04	19.80	34.90	20.30	35.76
.31	.34	.81	.20	.31	.06	.81	.92	.31	.78
.32	.36	.82	.22	.32	.08	.82	.94	.32	.80
.33	.37	.83	.23	.33	.09	.83	.95	.33	.82
.34	.39	.84	.25	.34	.11	.84	.97	.34	.83
.35	.41	.85	.27	.35	.13	.85	34.99	.35	.85
.36	.42	.86	.29	.36	.15	.86	35.01	.36	.87
.37	.44	.87	.30	.37	.16	.87	.02	.37	.88
.38	.46	.88	.32	.38	.18	.88	.04	.38	.90
.39	.48	.89	.34	.39	.20	.89	.06	.39	.92
18.40	32.49	18.90	33.36	19.40	34.22	19.90	35.07	20.40	35.93
.41	.51	.91	.37	.41	.23	.91	.09	.41	.95
.42	.53	.92	.39	.42	.25	.92	.11	.42	.97
.43	.55	.93	.41	.43	.27	.93	.13	.43	35.99
.44	.56	.94	.42	.44	.28	.94	.14	.44	36.00
.45	.58	.95	.44	.45	.30	.95	.16	.45	.02
.46	.60	.96	.46	.46	.32	.96	.18	.46	.04
.47	.61	.97	.48	.47	.34	.97	.19	.47	.06
.48	.63	.98	.49	.48	.35	.98	.21	.48	.07
.49	.65	.99	.51	.49	.37	.99	.23	.49	.09

After: Strickland, J.D.H., and T.R. Parsons. A Practical Handbook of Seawater Analysis. Fisheries Research Board of Canada, Ottawa. 1972.

3. What is the best estimate for the salinity of your sample using your data alone? Explain in your choice.

4. What is the best estimate for the salinity using the data gathered by the whole class? Explain your choice.

5. If an aliquot (sample fraction) with more or less than 10 ml were used (Ex - 15ml), what additional computations must be made?

6. Assume that too much $AgNO_3$ was added to the contents of the flask. How could the experiment be "saved"?

7. How can the fresh water outflow from a stream be traced at sea?

8. How could one determine the salinity tolerance of a marine organism?

9. How could a "Living Salinometer (a meter which determines salinity)" be compiled from the salinity preference of marine organisms?

10. What are two ways in which a marine organism could deal with changes in the salinity of its environment?

DATA SHEET

Salinity Determination

Titration Method

Name ____________ Date ____________ Time ________ 24 Hr. Clock

Water Depth of Sample: ____________ Water Temperature ________ C°

Air Temperature ________ Wind Speed ________ Wind Direction ________

Tidal Conditions: Flooding ________ Ebbing ________ Slack ________

Low ________ 1st Qtr. ________ Half ________ 3rd Qtr. ________ High ________

Sample # 1	Sample # 2
Buret readings:	Buret readings:
start ____________	start ____________
finish ____________	finish ____________
Number of mls of $AgNO_3$ used ____________	Number of mls of $AgNO_3$ used ____________
Salinity ____________	Salinity ____________
Correction ____________	Correction ____________
Corrected Salinity ____________	Corrected Salinity ____________

(A) Difference between the two samples ________________ o/oo

(B) Average salinity of the two samples ________________ o/oo

You can find the average by using this formula:

$$\frac{(\text{corrected salinity \#1}) + (\text{corrected salinity \#2})}{2} = \_\_\_\_\_\_\_\_ \text{ o/oo}$$

(C) Percent Error $\frac{(A)}{(B)} \times 100 =$ ________________ %

TEACHER BACKGROUND - pH Determination of Sea Water

The exercise "pH Determination of Sea Water" provides a look at an important chemical factor influencing life. Sea water is a mixture of solutes (dissolved substances) in the distilled water solvent. The final pH depends upon the excess of hydrogen (H^+) or hydroxyl (OH^-) ions in solution. All species of marine plants and animals have a pH tolerance. Some organisms have a "broad" tolerance, (i.e. pH values of 8.0± 1.5); and some have an extremely "narrow" pH tolerance. Fortunately, the negative ions of "weak" acids present in sea water tend to resist large changes in pH. These ions tend to "buffer" the sea water solution.

Many factors influence the pH of sea water. For example, water with large numbers of water plants tends to have higher pH values than those without. On the other hand, waters having dissolved clays generally have lower values.

If the student has studied chemistry, much of the background material will be familiar. Otherwise, this exercise should extend and reinforce the acid-base relationship. If you employ the pH meter method technique, keep in mind the fact that your own pH meter has specific characteristics. The instructions accompanying the instrument should be followed in preference to these. Be aware that the pH of sea water has idiosyncrasies differing from wtaer solutions containing a single dissolved substance.

The O_2, CO_2, CO_3^{-2}, HCO_3, H^+, OH^-, the metallic ions (K^+, Na^+, $Ca^{+}2$) and waste product ions make this sea water mixture as complex as our own body fluid. Indeed, it has often been compared to blood. Thus,to seek out one relationship between only two related ions (H^+, OH^-) is a gross simplification.

Most instruments and student titrations should produce accuracies of ± 1 pH. Standard solutions prepared with saline solvents will induce a more accurate pH instrument standardization. The buffers should bracket the expected pH of 8. A single buffer at a pH of 7, 8 or 9 may be used.

While pH meters are often available in high schools, this activity may be completed using pH paper, or other available pH kits. pH Hydrion paper covering the range of sea water is available. Try them first on saline water of know pH. Which ever method you employ, recall that: standardized solutions must be carefully prepared and stored; clean glassware is essential; and, solutions become contaminated easily.

Duplicate the activity pages. One set per student is recommended. Encourage careful experimentation to achieve reproducible results. If you do not have immediate access to natural sea water, you can prepare artificial sea water using the following receipe:

Synthetic Sea Water

Dissolve:

310 g. of analytical reagent quality sodium chloride ($NaCl$);
100 g. or analytical reagent quality magnesium sulphate ($MgSO_4 \cdot 7H_2O$); and,
0.50 g. of sodium bicarbonate ($NaHCO_3 \cdot H_2O$)

in 10 liters of distilled water.

Alternatively, you can purchase ready to mix sea salts for marine aquaria from an aquarium shop. Follow the manufacturer's instructions.

The idea of pH and logarithms can be confusing for your students. Be prepared to offer further explanation as needed.

The prevailing relationship between H^+ and OH^- is shown in two ways.

1. $H^+ + OH^- \longrightarrow H_2O$ and $H_2O \longrightarrow H^+ OH^-$
2. The number of H^+ times the number of OH^- ions equals a constant number at a given temperature pressure and volume of water.

Looking again at number 2 above, write $[H^+] \cdot [OH^-] = .00000000000001 = 10^{-14}$ as the constant. If your students are familiar with the principles of scientific notation, you might have them recall from algebra that $X^4 \cdot X^3 = X^7$ and $X^{-4} \cdot X^{-3} = X^{-7}$. Therefore, if the hydrogen ion concentration, $[H^+]$, can be written as 10 raised to some power and the hydroxyl ion, $[OH^-]$, is done likewise, then $[H^+]\,[OH^-] = 10^{-14}$ can be done by adding the powers of ten. Since the "powers" system is designed for dilute solutions, the actual power of ten is usually negative (less than one). For economy of effort, we change the sign on the power to plus (we algebraically invert the equation). For example, $[H^+] = 1/10$ mole per liter (.1g) $= 10^{-1}$ is now called pH = 1 (the "p" is for "power") while pOH = 13 so that pConstant = 14. HENCE, pH + pOH = 14.

Provide additional solutions for pH determination. Plan to allow time for a discussion of the experimental results and the "Analysis and Interpretation" section.

KEY

Text questions

1. The solutes in sea water come from dissolved rocks, soils, minerals and plant and animal materials carried by rivers into the oceans.
2. A pH 2 solution has 100 times the H^+ ion concentration of a pH 4 solution.
3. The pH of human blood is about 7.4.
4. The symbol $[OH^-]$ represents the amount of OH^- ions in one liter at 25° C and at one atmosphere of pressure.
5. The pOH of wine is 10.6 (i.e., 3.4 + pOH = 14; pOH = 10.6).
6. Lowering the pH makes the waters more acidic. This is a confusing concept to most students: the lower the pH number, the higher the acidity.

Analysis And Interpretation:

1. Answers depend upon experimental results. The pH of sea water is slightly alkaline, usually about 8.0.

2.&3. Answers depend upon experimental results. The merits of pooling data and replicating samples deserve discussion here. There are many possible sources of error, from recording errors to technique errors to sampling errors. Use this question as a springboard for discussion about sources of error and how to minimize these sources in an experimental situation.

4. We could use pH to help locate animals by finding areas with a pH that would be similiar to that preferred by the animal. Theoretically, we could herd and capture animals by changing the pH and driving them into certain areas.

5. A comparison of stream pH with the pH of effluent from the plant could help identify the culprit. This would not normally be sufficient evidence to indict! A discussion of environmental detective work via chemistry might prove interesting at this point.

6. The electrodes need to be washed in the buffer so that you have the same baseline from which to begin your investigations of pH.

KEY WORDS

acid
acidity
alkaline
alkalinity
atmosphere
average
basic
buffer
concentration
constant
disassociates

distilled

environment

hydrogen ion

hydroxyl ion

indicators

insoluble

logarithmic

neutrality

pH

pOH

polluted

solutes

solution

solvent

titration

variation

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PERIODICAL

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TEACHING AID

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pH DETERMINATION OF SEA WATER

Sea water is distilled water polluted by dissolved rocks, soils, minerals and organic (plant and animal) materials. These materials enter the water during its downhill rush to the sea. The dissolved materials are in the form of ions, dissolved gases, and compounds. Sea water, then, is a mixture of solutes (dissolved substances) with the "distilled" water solvent.

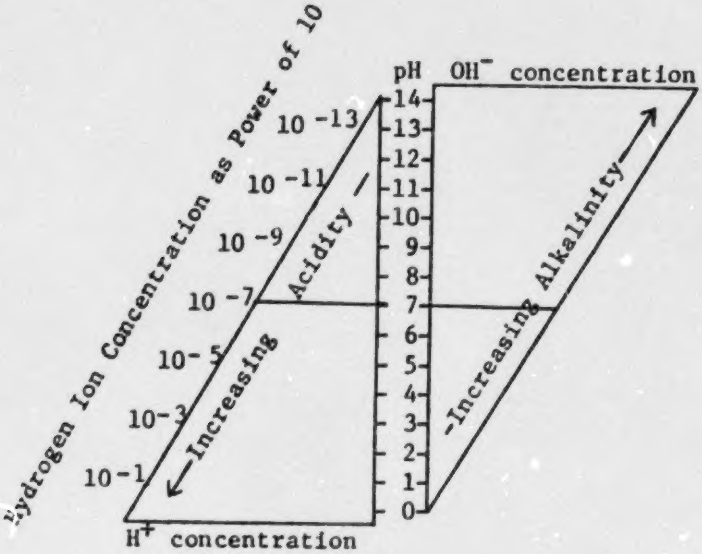
Water is an interesting substance. Pure distilled water dis-associates ("breaks") into hydrogen (H^+) and hydroxyl ions $(OH)^-$ of equal number. If the concentration of H^+ is greater than the OH^- concentration, the solution is acidic. If the H^+ concentration is less, the solution is considered alkaline. Equal numbers of OH^- and H^+ in a solution make the solution "neutral."

1. Where do the solutes in sea water come from?

Everyone who uses the term "pH" has an idea that it has to do with the degree of acidity. Not all realize that a change of one pH number is a change of the H^+ ion concentration by a factor of 10. That is: A pH of 5 has 10 times the H^+ ion concentration of a pH of 6. In a like manner a pH value of 7, although it represents "neutrality" is 1000 times as acidic as a pH of 10.

2. How many more H^+ ions are in a pH 2 solution than in a pH 4 solution?

The pH scale, then, is a logarithmic scale. Each pH number differs from the next by a factor of 10. The neutral position is 7 on a 1 through 14 scale. The numbers 1 to 7 indicate the acid range, and the numbers above 7 to 14 represent the alkaline range. Keep in mind that by the use of a logarithmic scale, a unit change in pH corresponds to a tenfold change in the hydrogen ion and hydroxyl ion concentrations.


Hydrogen Ion Concentration as Power of 10
10 -13
10 -11
10 -9
10 -7
10 -5
10 -3
10 -1
Increasing Acidity
H+ concentration
pH
OH- concentration
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Increasing Alkalinity

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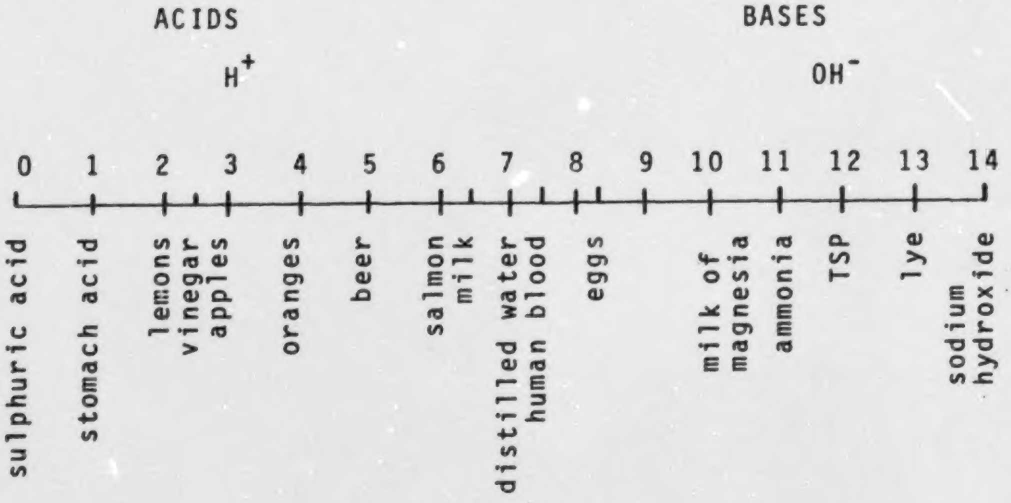
pH of Some Common Items



3. What is the pH of human blood?

Then, what is pH? pH is a "short hand" way of accounting for the available acid ion (H^+). In a like manner, there exists a related pOH to do the same for the available basic ion $(OH)^-$. The prevailing relationship between H^+ and OH^- is shown in two ways.

A. $H^+ + OH^- \longrightarrow H_2O$ and $H_2O \longrightarrow H^+ + OH^-$

B. The number of H^+ times the number of OH^- ions equals a constant number at a given temperature, pressure and volume of water.

For ease of comparisons chemists define the standard conditions as:

Temperature - 25°C - (about room temperature)

Pressure - One atmosphere

Volume - One liter

Thus $[H^+]$ is a symbol representing the amount of $[H^+]$ ions in one liter at 25°C and at one atmosphere of pressure. You can now identify $[OH^-]$.

4. What does the symbol $[OH^-]$ represent in standard conditions?

At 25°C and one atmosphere of pressure the number of H^+ ions times the number of OH^- ions equals .00000000000001 or 10^{-14} (i.e., $[H^+] \cdot [OH^-] = .00000000000001 = 10^{-14}$). The number 10^{-14} represents a constant relationship between $[H^+]$ and $[OH^-]$. Because the pH scale is logarithmic, pH + pOH = 14.

5. Under standard conditions, the pH of wine is 3.4. What is the pOH of the wine?

Why is pH important? Seventy-five percent of the earth's surface is best operated at a pH of 8 to 8.3. Your own blood must also have a constant pH. Organisms are subject to considerable change if there are changes in the acidity (or alkalinity) of their waters.

The chemical processes that occur in living cells are carried on in solutions near to neutrality. The cells of plants and animals have special mechanisms to maintain a constant hydrogen ion concentration. These mechanisms are called buffers. These buffer systems keep the fluids relatively constant. These buffer systems, however, have no control over the external environment. The pH of an organism's surroundings often changes. The buffer systems within the organism must be able to keep the internal environment constant in the face of these external changes.

Normal changes in pH are now accompanied by local drastic changes. For example, many industrial plants discharge pollutants that lower the pH of the waters. The pH is oftentimes lowered below the point where desirable organisms can live. It therefore becomes important to measure the external environment in terms of acidity and alkalinity. The nature of the pH limits the kinds of organisms which can exist.

There are three techniques which can be easily employed to measure the pH of sea water:

1. pH paper;
2. pH meters; and,
3. titration.

In the following activities you will determine the pH of sea water.

6. If industrial plants lower the pH of waters, are they making the waters more acidic or more basic?

Materials:

pH test papers

clean labware

pH meter

buffers (solutions of known pH)

distilled H_2O and samples

Procedure:

pH Meter

1. Obtain a sample of sea water.
2. Refer to the instructions from the manufacturer for the specific technique for use with your pH meter. The following are general hints for operating the meter and getting the best results:

   A. Standardizing the meter:

      1. Check the meter to see that it is plugged to a "hot" outlet. (For portable meters: check the battery).
      2. Allow warm-up period (5-10 minutes).
      3. Rinse electrodes with distilled water. Wipe dry with soft, lint-free tissue.
      4. Rinse electrode with small amount of standard buffer. Note: a marked wash bottle containing buffer from previous standardizations is handy for this. REMEMBER: Never pour used buffer back.
      5. Immerse electrodes in buffer solution. Now take the temperature of buffer. If instrument has a temperature correcting dial, set to existing temperature. Otherwise, record temperature.
      6. Activate pH "Read Control".
      7. Rotate knob marked "Adjust" or "Standardize" until meter reads the correct pH.
      8. Release pH "Read Control".

B. Reading of pH sample:

1. Rinse electrodes with a small amount of sample.
2. Immerse electrodes in sample.
3. Take temperature of sample.
4. Activate pH "Read Control".
5. Record pH reading.
6. Release pH "Read Control".
7. Rinse electrodes with distilled H_2O and wipe.

3. Record the pH on your data sheet.
4. Repeat the procedure with a second sample from the same location.

pH Paper

1. Tear off 2 inches (5cm) of pH paper.
2. With a clean pipette place 2-3 drops of the water sample on one end of the pH paper.
3. Visually compare the wetted end with the chart standard accompanying the pH paper.
4. Record result on your data sheet.
5. Repeat steps 1-4 with a second sample from the same location.

The use of pH papers is largely confined to determining large variations in acidity. The pH meter is most often used where the pH determination is required for a detailed analysis. If we were interested in determining if the water in a swimming pool was "safe", we could use pH papers. On the other hand, if we wanted to know how the addition of a certain chemical to water affected the pH, we would want to use a pH meter.

Analysis and Interpretation:

Complete the following data record for your sample:

Sample number:

Date:

Depth:

Noted inhabitants (plants and animals):

Collector:

Hour: pH sample 1 ___________ sample 2 _____________.

Temperature:

Climatic conditions:

1. What was the average pH of your samples?

2. Obtain data from other students by writing your results on the blackboard. What was the class average?

3. Was your average the same as that of the class? If not, what are two possible sources of the difference (variation) in results?

4. The pH affects where animals and plants can live. How could we use pH to help locate and capture animals?

5. If two industrial plants were upstream from a "fish-kill", how could a pH study identify the culprit?

6. Why should the electrodes be washed in the buffer and sample as recommended in the procedure?

TEACHER BACKGROUND - Oxygen

Oxygen is essential to most organisms. The determination of the oxygen content of sea waters provides your students with practice in some fundamental chemical procedures while gathering data which can be used to discuss the general conditions necessary for life in the oceans. The procedure used is a modification of the Winkler Titration method. You may have access to oxygen meters or field kits, such as those produced by LaMotte Scientific or Hach Chemical, in which case you should refer to the directions provided by the manufacturer.

The theory behind the technique and the procedures for making the standard solutions are included in this section. Prior to performing the investigation, introduce your students to the role of oxygen in the marine environment. The first section of the activity may be assigned as background reading. If you are able to have your students collect the water for testing, demonstrate the use of the water sampler. Discuss the apparatus and demonstrate the techniques involved in determining oxygen concentration. Allow your students to practice the use of the equipment by determining the dissolved oxygen concentrations of aquaria in the classroom. Provide any help your students may need as they follow the procedure outline. Discuss the problems encountered in the use of the equipment and rectify the problems encountered. Emphasize the need for care in the performance of these tests. Plan to allow time for a discussion of the results and the procedure at the end of this activity.

KEY

Text questions

1. Oxygen enters sea waters in two ways: directly from the atmosphere above the water, and from plant photosynthesis during daylight hours.
2. Respiration is important since it provides oxygen required for the energy deriving oxidation processes carried on by living organisms. The energy is used for all of life's processes.
3. Water samples should be taken at several depths rather than at a single depth, since factors such as oxygen often change with depth.
4. Minimizing the mixing reduces the amount of oxygen that enters the water sample by diffusion at the surface.

5. In the Winkler Titration method for the determination of dissolved oxygen, the quantity of iodine is actually measured.

Analysis and interpretation

1,2,3. The answers depend upon the experimental results obtained.

4. Lowest concentrations would be found when the water is the warmest, saltiest, and most full of dissolved organic matter. Most often, these conditions would occur in late summer or early fall.

ONE STEP FURTHER........

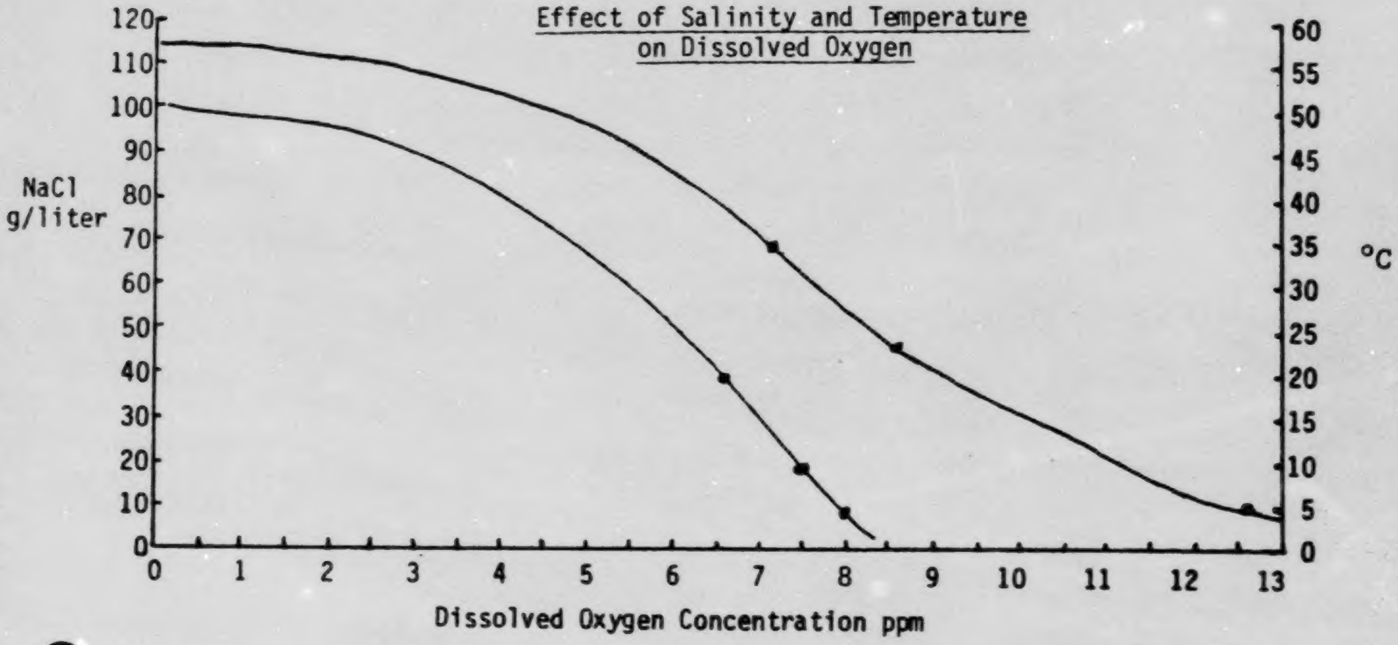
"One Step Further...." and "More One Step Further...." offer your students an opportunity to employ the techniques learned in "Oxygen" to study the effect of various factors on the dissolved oxygen concentration of water samples.

Analysis and Interpretation

1. The answer depends upon the experimental results. Usually, the tap water solution will have the highest dissolved oxygen concentration.
2. The answer depends upon experimental results. Usually, the stoppered flask with the organic matter solution will have the lowest oxygen concentration.
3. A generalization might be: Decaying organic matter causes a decrease in the dissolved oxygen concentration of a water sample. This question might serve as a starting point for a refresher course on the process of science.
4. a. The dissolved oxygen concentration near the discharge of the super sewer would decrease. The D.O. would be lower than that of surrounding waters.
    b. As you move away from the outfall, you would predict an increase in the dissolved oxygen concentrations of the water.
    c. Plant and animal populations will change in the area of the sewer outfall. Organisms requiring a high oxygen content will no longer be found. Those that can survive in areas of low oxygen concentrations will become more numerous.
5. Constant or very frequent monitoring of the waters near a sewer outfall can show us the point when the waters will no longer tolerate the addition of more organic matter. Once we determine the loading limits, we can hopefully regulate the discharge accordingly.

Analysis and Interpretation:

1. The graph depends upon the experimental results, but should have the following general appearance:



Effect of Salinity and Temperature on Dissolved Oxygen

2. A generalization which may be derived from the experimental results might be phrased: Increased salinity decreases the ability of water to hold dissolved oxygen.
3. A generalization which may be derived from the second set of experimental results might be: Increased temperature decreases the ability of water to hold dissolved oxygen.
4. a. The increased temperature will tend to decrease the dissolved oxygen concentration.
   b. The decreased salinity will tend to increase the dissolved oxygen concentration.
   c. The decrease in dissolved oxygen concentration due to the increased temperature will be, at least partly, offset by the increase in dissolved oxygen concentration due to the decrease in salinity. The factors interact in such a way as to have the potential for decreasing the effect of the discharge on the dissolved oxygen concentration.
   This question provides a good opportunity for a discussion of the effects of interaction between environmental factors. While we normally only examine a single factor at a time (e.g., salinity or dissolved oxygen), in real life these factors all interact to influence the plants and

animals living in an area. It is interesting to note that the number of interactions between factors increases according to the formula:

$$N = 2^{\frac{n(n-1)}{2}}$$

where N is the number of interactions and n equals the number of factors being considered. For example, for five interacting factors, there are a possible 2^{10} or 1024 interactions. This sobering information should tend to make us cautious in our predictions regarding the effects of man-made projects on the ocean ecosystem.

Determination of Dissolved Oxygen:

The following is a discussion of the procedure for the titrametric determination of dissolved oxygen concentration. You may find that you will have to make certain compromises as you do your oxygen determinations. Each alteration in the procedure decreases the precision. This, however, should not be looked upon with great alarm. While the results you obtain with modifications may not be analytically accurate, with reasonable care your results should provide a good picture of the water studied and also provide a good springboard for discussion.

A. Outline of Method

The Winkler Titration method involves chemical treatment of the water sample in such a manner that one molecule of iodine is produced in the sample for each molecule of oxygen in the original sample. The concentration of iodine is then determined by titration. In the technique a divalent manganese solution, followed by strong alkali, is added to the sample. Manganous hydroxide is precipitated out. The precipitate is agitated to evenly disperse it. The sample completely fills a stoppered glass bottle. Any dissolved oxygen in the water rapidly oxidizes an equivalent amount of divalent manganese to basic hydroxides. The solution is next acidified in the presence of iodide. The oxidized manganese liberates iodine. The amount of iodine is equivalent to the original dissolved oxygen content of the water. This iodine is titrated with standardized thiosulphate solution.

B. Sampling Procedure and Sample Storage

Three hundred milliliter Biological Oxygen Demand (BOD) bottles are rinsed twice with the sample being analyzed. If the sample is obtained from a reversing bottle, a length of rubber tubing should be taken from the tap to the bottom of the BOD bottle and sea water introduced in such a way as to minimize turbulence and agitation of the sample. The end of the rubber tube must always be kept beneath the surface of the water as the bottle is filled. Water is allowed to overflow from the top of the BOD bottle which is stoppered at once. A volume of water at least equal to the volume of the BOD bottle should be allowed to overfow, more if the oxygen content of the water is suspected to be very low. No air should remain in the bottle. When the sample is taken from a bucket (e.g., surface samples), rinse the bottle twice and then allow the water to flow in by submerging the bottle to the mouth and gently tipping it so that the sample enters with no bubbling and a minimum of turbulence. For work of the highest accuracy, the sample should be siphoned into the bottle.

Store the samples in the dark or in subdued light to minimize photosynthesis by any phytoplankton that may be present. If the analysis must be delayed, "pickle" the samples by adding the manganous sulphate and alkaline iodide azide solutions. The rest of the analysis may be completed at leisure.

C. Special Reagents

1. Manganous Sulphate Reagent

Dissolve 480 g of manganous sulphate tetrahyde, $MnSO_4 \cdot 4H_2O$, or 400 g of manganous sulphate dihydrate, $MnSO_4 \cdot 2H_2O$, or 364 g of manganous sulphate monohydrate, $MnSO_4 \cdot H_2O$, in distilled water. Filter and dilute the volume to 1 liter.

2. Alkaline Iodide Solution

Dissolve 500 g of sodium hydroxide in 500 ml of distilled water. Dissolve 150 g of potassium iodide in 200-300 ml of distilled water in a separate container. Mix the two solutions. A great deal of heat will be liberated. Dilute to 1 liter. To this solution, add 10 g sodium azide, NaN_3, dissolved in 40 ml of distilled water. This reagent should not give a color with starch solution when diluted and acidified.

3. Sulfuric Acid

   Use concentrated reagent grade sulfuric acid, H_2SO_4. Handle with care!

4. Starch Solution

   Prepare a paste of 5-6 g soluble starch in a small amount of distilled water. Pour this paste into 1 liter of boiling distilled water. Allow the paste and water to boil a few minutes and let settle overnight. Use the clear supernatant. This solution may be preserved with 1.25 g salicylic acid/liter or by the addition of a few drops of toluene.

5. Sodium Thiosulfate Stock Solution, 0.10 N

   Dissolve 24.82 g $Na_2S_2O_3 \cdot 5H_2O$ in boiled and cooled distilled water and dilute to 1 liter. Preserve by adding 1 g NaOH/liter.

6. Working Sodium Thiosulfate Titrant, 0.025N

   Dilute 250 ml sodium thiosulfate stock solution to 1 liter.

7. For standardizing the sodium thiosulfate with $K_2Cr_2O_7$ solution

   Dissolve approximately 2 g KI, free from iodate, in an Erlenmeyer flask with 100 to 150 ml distilled water. Add 10 ml of 3.6N H_2SO_4 followed by exactly 20 ml of standard dichromate solution (reagent, step 8) and place in the dark for 5 minutes. Dilute to 400 ml and titrate with the 0.025N thiosulfate, adding starch toward the end of the titration when a pale straw color is reached. If the sodium thiosulfate is 0.025N, exactly 20 ml of this titrant will be required to reach the titration endpoint. If necessary, adjust the sodium thiosulfate to 0.025N by adding $Na_2S_2O_3 \cdot 5H_2O$ if the above titration required more than 20 ml. If the titration required less than 20 ml, add boiled and cooled distilled water. Again, check by titration.

8. Standard Potassium Dichromate Solution, 0.025N

   Weigh out 1.226 g of $K_2Cr_2O_7$, previously dried in an oven at 103°C for 2 hours. Prepare the solution in a volumetric flask by diluting the $K_2Cr_2O_7$ to a liter. A solution of $K_2Cr_2O_7$ equivalent to 0.025N sodium thiosulfate contains 1.226 g/liter $K_2Cr_2O_7$.

   Additional information may be found in:

   Strickland, J.D.H. and T.R. Parsons, 1972,
   A Practical Handbook of Seawater Analysis,
   Fisheries Research Board of Canada: Bulletin 167, Ottawa.

KEY WORDS

activated sludge
alkaline-iodide-azide solution (AIA)
biological oxygen demand (BOD) bottles
burette
chlorinity
concentration
consolidating
dissolved oxygen (DO)
end point
Erlenmeyer flask
generalization
graduated cylinder
interactions
iodine
limnologists
manganous sulfate ($MnSO_4$)
nomograph
organic matter
oxygen
photosynthesis
pipettes
precipitate
reagents
respiration
salinity
saturation
sewage
sewer outfall
sodium thiosulfate
solubility
sulfuric acid (H_2SO_4)
supernatant
thermocline
titrant
titration
Winkler titration method

OXYGEN

Of all the chemical substances in natural waters, oxygen gas is one of the most important to life. Both animals and plants need oxygen for respiration. Respiration is the process of combining foods with oxygen to obtain energy for life's activities. Oxygen enters sea waters in two ways: directly form the atmosphere (air) above the water; and, from plant photosynthesis during daylight hours. Since about 21% (210 ppt) of the air is oxygen, one might expect that the water would have a similar percentage of dissolved oxygen. Actually, we find that water will only hold about .001% (10 ppm) oxygen - 210 times less oxygen than air! It is not difficult to see that the primary life limiting gas in water is oxygen. Land dwelling animals seldom die from a lack of oxygen in the air. Water dwelling organisms often die from a lack of oxygen in the water.

1. How does oxygen enter sea waters?

The amount of dissolved oxygen is affected by factors such as temperature, salinity and dissolved organic matter (e.g., sewage, etc.). An increase in any of these factors tends to decrease the amount of oxygen the water can hold and, therefore, the amount of oxygen available to plants and animals.

2. Why is respiration important for living things?

Unlike water in a fish tank where a sample taken at any portion would be similar in its properties to a sample of water taken from another portion, sea waters can vary considerably from area to area. Perhaps you have had the opportunity to dive into a lake in the spring and have noticed that as you reach a certain depth, you will contact a layer of very cold water. This is called the thermocline. Such layering of waters due to temperature is common. Variations of the other physical and chemical factors are also common. It is therefore necessary, when studying the properties of a water system, to analyze samples at different depths at the same station. Often populations of different animals and plants are restricted to different depths because of these environmental conditions. As you carry out tests to determine the various properties of water taken at a given station, it is important that you include information on the properties of the waters at the station at various depths.

3. Why should you take water samples at several depths rather than at a single depth?

Since the water is to be analyzed for dissolved oxygen, your sample must be collected in such a fashion that air is not bubbled through the sample. Oceanographers and limnologists, those who study fresh water, have developed special equipment for gathering such samples. Your instructor will demonstrate the use of the equipment you will be utilizing. In all samples, the water should be taken from the sampler in a fashion which prevents or minimizes mixing.

4. Why do you want to minimize the mixing?

The water sample of at least 500 ml should be carefully run into a glass stopper bottle of at least 250 ml capacity by inserting a delivery tube in the bottom of the bottle. The water should be allowed to overflow until the sample bottle has had several volumes of water passed through it to flush out the atmospheric oxygen. When the bottle is filled, the glass stopper is inserted carefully to avoid the introduction of any air bubbles. This can be easily accomplished by tipping the bottle slightly and then inserting the stopper at an angle with a quick downward thrust. A record of the water temperature in the collecting sample must be taken at this time for further use.

You will be using the Winkler Titration method to determine the dissolved oxygen concentrations of your water sample. The Winkler method is one of the most common techniques used for determining the dissolved oxygen content in water. This technique involves the formation of an amount of iodine equivalent to the amount of oxygen originally present in the bottle. One molecule of iodine is formed for each molecule of oxygen present in the sample. Determining the amount of iodine, then, gives us the amount of oxygen present in the water sample.

5. In the Winkler Titration method for the determination of dissolved oxygen, the quantity of (oxygen/iodine) is actually measured. (Cross out one of the terms to make a correct sentence.)

Materials:

300 ml Biological Oxygen Demand (BOD) bottles or 250-300 ml Erlenmeyer flasks with stoppers.

Thermometer.

3 pipettes, 2 or 5 ml with graduations; marked as follows:

$MnSO_4$

AIA

H_2SO_4.

10 ml, 50 ml and 250 ml graduated cylinders.

50 ml burette graduated in 0.1 ml divisions.

250 or 500 ml Erlenmeyer flask.

Reagents:

Manganous sulfate solution ($MnSO_4$)

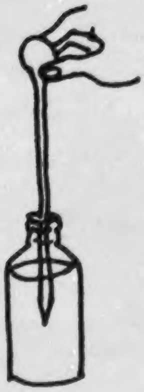
Alkaline-Iodide-Azide solution (AIA)

Sulfuric acid (concentrated) (H_2SO_4) Handle with care!

Starch solution

Sodium thiosulfate titrant ($Na_2S_2O_3$).

Procedure:



Note: When adding reagents (chemicals), use the pipette which is clearly marked with the name of the reagent. The pipette should be inserted well into the bottle (below the surface of the H_2O) to prevent the reagent from spilling over. (The reagents are heavier than H_2O and sink to the bottom of the bottle.) Gradually withdraw the pipette, making certain that all the reagent has been released below the neck of the bottle.

1. Carefully collect a water sample as previously described.
2. Record the water temperature.

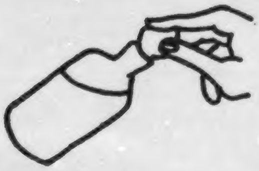
3. Remove the glass stopper from the water sample bottle and to the sample add:

   2 ml of Manganous Sulfate (use the pipette labeled $MnSO_4$) followed by

   2 ml of Alkaline-Iodide-Azide solution (use the pipette labeled AIA).

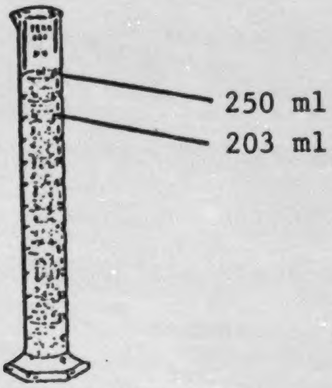
   Pipette below the surface of the sample. Be careful not to stir up the sample.

4. Carefully replace the stopper, being careful to avoid the introduction of air. This can be easily accomplished by tipping the BOD bottle slightly and then inserting the stopper at an angle with a quick downward thrust. Mix the contents by inverting the bottle 15 times. A brown precipitate should appear. The dissolved oxygen is now "fixed." If collecting in the field, this step should be performed immediately after collection.



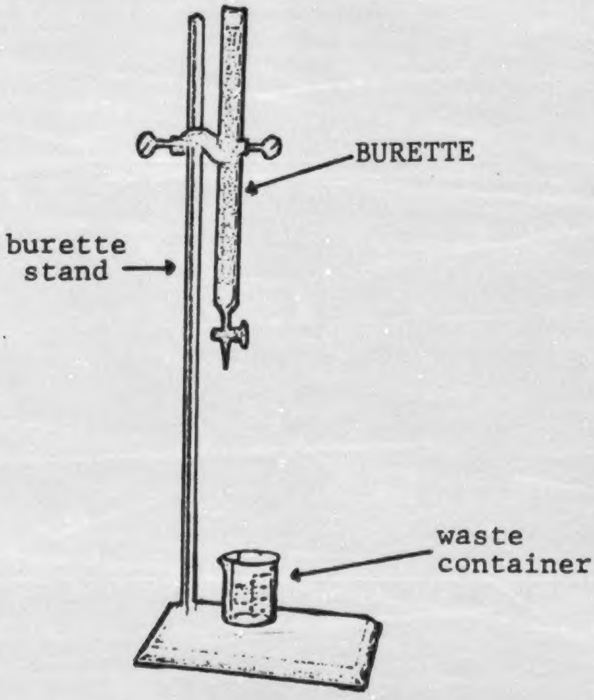
5. CALL YOUR INSTRUCTOR BEFORE CARRYING OUT THIS STEP: Allow the precipitate to settle, leaving about 100 ml of clear supernatant solution above the precipitate. Carefully remove the stopper and immediately add 2 ml of concentrated sulfuric acid. Let the acid run down the inside neck of the bottle. Restopper and mix by inverting the bottle slowly. The precipitate should dissolve. If it does not, add another 0.5 ml of the acid, stopper and shake. (The yellowish color which remains represents the iodine which has replaced the dissolved oxygen. If the solution is colorless, there is no dissolved oxygen in the sample.)

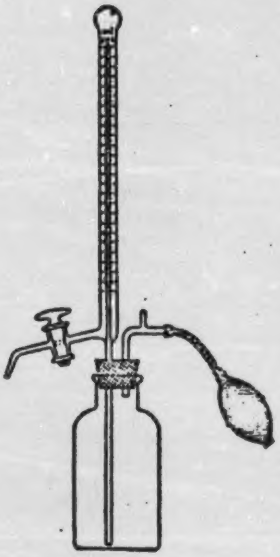
6. Measure out 203 ml of the sample using a graduated cylinder. Pour this solution into a clean 250 ml or 500 ml Erlenmeyer flask.


250 ml
203 ml

GRADUATED CYLINDER

7. Fill a burette with the sodium thiosulfate ($Na_2S_2O_3$) solution. Run a small volume through the burette into a waste container to free the burette of air bubbles. RECORD the level of sodium thiosulfate in the burette on the Data Sheet.


BURETTE
burette stand
waste container



AUTOMATIC BURETTE

8. Add sodium thiosulfate drop by drop to the water in the sample flask. This dropwise addition is called "titrat[illegible]." To mix the solutions, swirl the flask as you titrate. STOP when the solution is straw yellow.
9. Add 2 ml of the starch solution. The sample will turn blue-black. (If it does not, you have added too much thiosulfate and must begin again.)
10. Continue titrating slowly until the sample becomes clear. Stop immediately. Swirl the flask as you add sodium thiosulfate.

    NOTE: One drop will cause the color change to occur. DO NOT continue to add sodium thiosulfate past this color change "end point."
11. RECORD the level of thiosulfate in the burette. Calculate the volume of thiosulfate used (beginning reading minus final reading). RECORD the volume of sodium thiosulfate used.
12. Determine the amount of oxygen in parts per million (ppm). The amount of sodium thiosulfate used is exactly equivalent to the dissolved oxygen concentration in the water. For example, if 7.5 ml of 0.025N thiosulfate was required to reach the end point, the dissolved oxygen concentration in the water is 7.5 parts per million (ppm).

    RECORD THE DISSOLVED OXYGEN CONCENTRATION in ppm on your DATA SHEET.
13. It is standard practice to obtain two identical samples from each depth. The ppm dissolved oxygen (D.O.) at each depth should theoretically be identical. In practice,

small variations will occur. If the ppm D.O. values obtained from the matched samples are close, one is reasonably certain that his results are accurate. Average the paired results and RECORD for each set of samples.

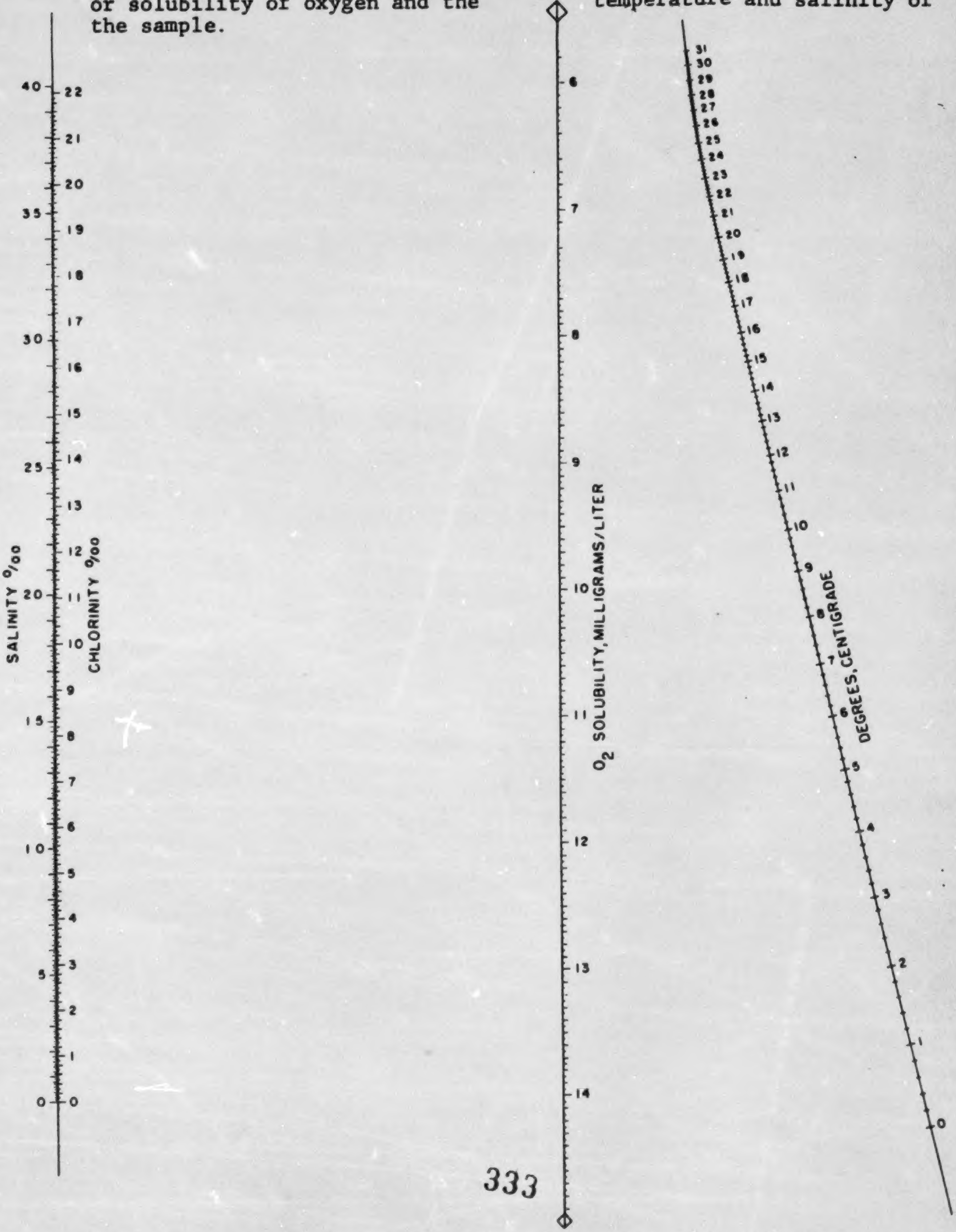
ANALYSIS AND INTERPRETATION:

While the dissolved oxygen concentration data you have obtained is interesting in itself, we are primarily concerned with the effect of this concentration on the organisms in the body of water sampled. The dissolved oxygen level can tell us much about the general "health" of the water and about its ability to support life. For example, low oxygen concentrations may mean high levels of sewage pollution since the breakdown of these wastes uses up (consumes) oxygen. Oxygen concentrations of 5 ppm or less can reduce fish growth and fish kills can occur as well. The minimum oxygen required for life depends upon the species of the fish as well as other environmental factors (e.g., temperature). Use the following nomograph to compare your results to the maximum concentrations expected for different salinities. You will need to obtain the salinity or chlorinity figures either by experimentation or from your teacher. If no figures are available, assume a salinity of 34.5 parts per thousand (o/oo).

1. How do your figures compare with the maximum saturation expected for your temperature?

2. If they are lower, what factors at your site might help explain the observations?

Nomograph illustrating the relationship between the saturation level or solubility of oxygen and the temperature and salinity of the sample.



Instructions: Connect two known values with a straight line to find the unknown.

3. If we assume that 5 ppm oxygen is the lower limit for survival of king salmon, would we expect to find any king salmon in the waters of your site?

4. At which time of the year would you expect to find the lowest oxygen concentrations? Why?

*American Public Health Association, etal, 1960, from calculation by Whipple and after Whipple (1911), based on measurements of Fox (1909).

OXYGEN DATA SHEET

SAMPLING DATE____________ SAMPLING TIME_________
(24 hour clock)

SCHOOL________________________ INSTRUCTOR_____________________________

TIDE: FLOODING___ SLACK___ EBBING___ SAMPLING (BOTTOM) DEPTH___M *WAVE HEIGHT____CM

TEMPERATURE: WATER SURFACE_____°C WATER BOTTOM_____°C AIR (30 CM (ONE FOOT) ABOVE WATER SURFACE)________°C

WEATHER CONDITIONS: *WIND SPEED____KM/HR *WIND DIRECTION (CIRCLE ONE) N NE E SE S SW W NW

CLOUD COVER: ______CLEAR _____TO 50% ____TO 90% ____100% COVERAGE VISIBILITY ____KM

	SAMPLE 1	SAMPLE 2
1. Record water temperature of sample.	________	________
2. Record depth at which sample was collected.	________	________
3. Record burette reading at beginning.	________	________
4. Record burette reading at end of titration.	________	________
5. Record volume of titrant used (#3 minus #4).	________	________
6. Determine ppm dissolved oxygen (# ml of titrant used = ppm dissolved O_2).	________	________
7. Determine the average dissolved oxygen concentration $\frac{(\#6 \text{ sample } 1) + (\#6 \text{ sample } 2)}{2}$.	________	________
8. Determine the difference in dissolved oxygen concentrations (sample #1 minus sample #2).	________	________

ONE STEP FURTHER.....

Now that you have mastered the Winkler technique, you can use your knowledge to examine how various things affect the oxygen concentration of water. Let's look at the effect of organic matter on dissolved oxygen. In addition to the materials required to perform the Winkler determination, you will need:

Materials:

500 ml of Erlenmeyer flasks (3)
stopper (1)
tap water
activated sludge from a waste treatment plant or other decaying organic matter, such as rotting leaves in a stream.

Procedure:

1. Add a twenty or thirty gram sample of organic matter to each of two of the Erlenmeyer flasks.
2. Fill all three flasks to the 500 ml line with tap water. Place a stopper in one of the flasks containing organic matter.
3. Set all three flasks aside and do not disturb for three days.
4. Fill labeled, dissolved oxygen bottles or 250-300 ml Erlenmeyer flasks with these samples.
5. Use the Winkler technique to measure the dissolved oxygen content of each of the three solutions. RECORD your results.

Analysis and Interpretation:

1. Which solution had the highest oxygen concentration?

2. Which solution had the lowest oxygen concentration?

3. State a generalization about the effect of organic pollution on the concentration of dissolved oxygen. A generalization is a statement that describes your results and lets you make predictions based upon your results.

4. There is growing tendency toward consolidating municipal sewer systems. These systems treat the organic wastes for a large area and then discharge the treated wastes into the ocean or other body of water via a "super sewer."

    a. Predict what the effect of such a super sewer would be on the dissolved oxygen concentration near the discharge.

    b. Predict what will happen to the dissolved oxygen concentration as you move away from the sewer outfall (the discharge site).

    c. From your predictions of the dissolved oxygen concentrations, predict what will happen to the plant and animal populations living in the area of the discharge.

5. How might the Winkler test for dissolved oxygen be helpful in determining how much sewage waste can be discharged into an area without damaging the existing plant and animal populations?

MORE ONE STEP FURTHER......

Can we determine the effect of salinity and temperature on the dissolved oxygen concentration of water samples? Sure. Just follow the steps below. In addition to the materials you will need for the Winkler technique, you will need:

Materials:

1000 ml Erlenmeyer flasks (4)
170 g salt (NaCl)
balance
tap water
refrigerator
incubator

Procedure: The Effect of Salinity

1. Obtain four 1000 ml Erlenmeyer flasks.
2. Prepare four salt solutions of 10, 20, 40 and 100 g NaCl/liter by dissolving the appropriate number of grams of salt in one liter of water. Label each solution as you make it.
3. Fill labeled dissolved oxygen bottles or 250-300 ml Erlenmeyer flasks with these solutions.
4. Measure the dissolved oxygen content of each salt sample. RECORD the dissolved oxygen content and the temperature for each sample. The temperature should be the same in all samples.

Procedure: The Effect of Temperature

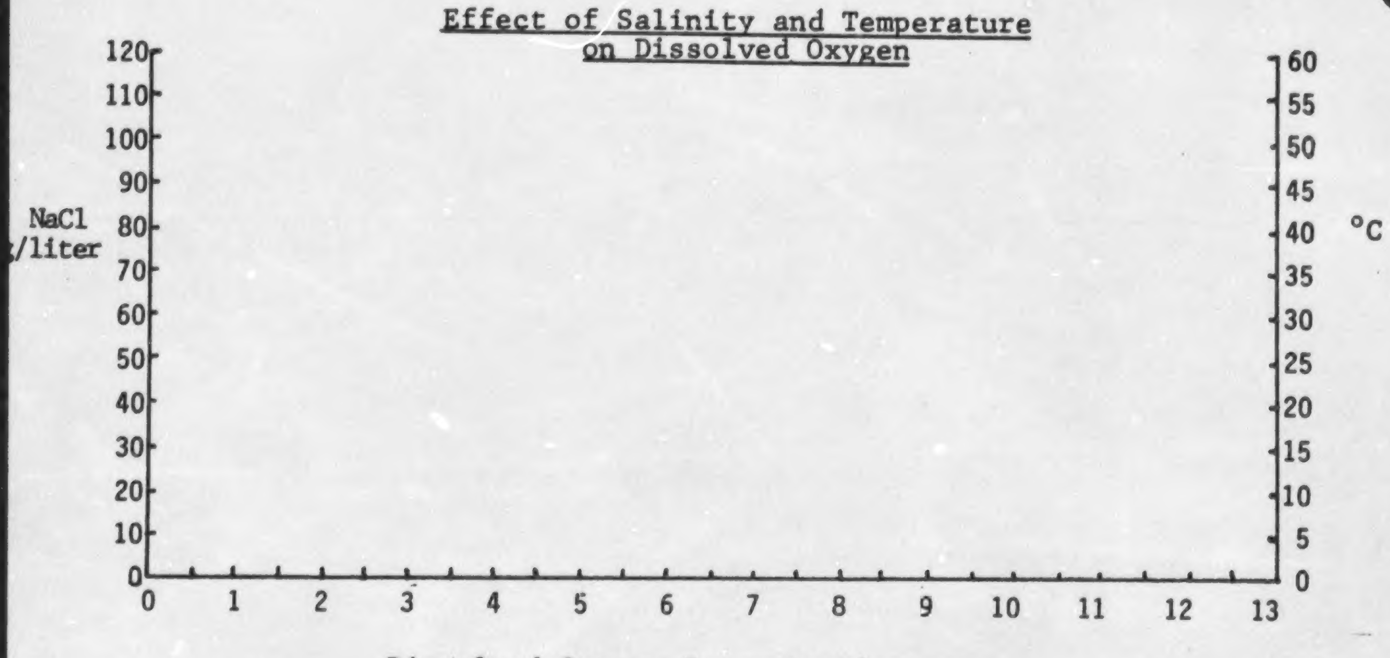
1. Obtain four clean 1000 ml Erlenmeyer flasks.
2. Use the refrigerator and incubator to adjust four water samples to the following temperatures:

4°C (refrigerator)	23°C (room temperature)
35°C (incubator)	60°C (incubator or hot plate)

3. Fill labeled dissolved oxygen bottles or 250-300 ml Erlenmeyer flasks with these four solutions.
4. "Fix" each of the four samples by performing steps one through four of the Winkler determination. Perform these steps as soon as possible and measure the temperature of the sample at that time.
5. After all of the solutions are fixed, titrate each solution using the Winkler technique. RECORD your results, for each sample.

Analysis and Interpretation:

1. Use the graph axes to plot your results. Plot the salinity results by using the left hand scale and the bottom scale. Plot the temperature results by using the right hand scale and the bottom scale.


Effect of Salinity and Temperature on Dissolved Oxygen

2. State a generalization relating to the effect of salinity on dissolved oxygen concentration. A generalization is a statement that describes your results and lets you make predictions based upon your results.

3. State a generalization relating to the effect of temperature on dissolved oxygen concentration.

4. Indianola Electric Company discharges hot, fresh water into the ocean.

   a. What effect will the increased temperature have on the dissolved oxygen concentration?

   b. What effect will the decreased salinity have on the dissolved oxygen concentration?

   c. It is important to realize that in real life, factors such as dissolved oxygen concentration are influenced by and interact with many other factors. How do the two effects of increased temperature and decreased salinity interact? Does their interaction increase or decrease the effect of the discharge on the dissolved oxygen concentration?

TEACHER BACKGROUND - Turbidity

Turbidity is a measure of the clarity of water. The more turbid or cloudy a water is, the shorter the distance the light can penetrate below the surface. Turbidity is influenced by the presence of suspended matter, such as clay, silt, finely divided organic matter, and microscopic plankton. Turbidity is a result of the absorption and scattering of light. Turbidity directly affects phytoplankton growth and thereby indirectly affects all life in the sea.

Of all the parameters of water analysis, turbidity determination is perhaps one of the most difficult for which to establish a satisfactory procedure. For field studies, the Secchi disc and photometrics have been used successfully.

Secchi discs vary in diameter between 8" (20 cm) and 7½ feet (237 cm). Many commercially produced ones are about 12" (30-33 cm) in diameter. One side is white, while the other side is either black or black-white marked in quadrants. General Biological Supply House (Turtox), Chicago, Illinois; and Gilson Slide Rule Co. of Stuart, Florida, now market a smaller Secchi disc of about 8" in diameter (22 cm). A workable Secchi disc may be "homemade" by employing the drawing in the student section as a construction plan from which to make your own Secchi disc from aluminum or plastic. The Secchi disc is also used by comparing the white disc at a standard depth (1M) to a color chart. The color chart is in two parts:

The Forel Scale I-X

The Ule Scale XI-XXII.

The Forel Scale is primarily for offshore blue to green waters. The yellowish to brown inshore waters match the Ule scale. These scales can be procured from Braincon Corp., Marion, Massachusetts, and other suppliers of oceanographic instruments. They may be made from chemicals available in most high school laboratories according to the following table and directions:

Prepare:

1210 ml of solution 1,
660 ml of solution 2, and
330 ml of solution 3.

Solution 1:

Measure 6.05 g of $CuCo_4.5\ H_2O$
Dissolve $CuSo_3.5\ H_2O$ in one liter of distilled H_2O.
Add concentrated NH_4OH until deep blue color indicates the complete dissolving of the white precipitate. Add NH_4OH* to complete dissolving of the white precipitate. Add NH_4OH* to 1210 ml.

Solution 2:

Measure 3.3 g of $K_2CrO_4.5\ H_2O$
Measure 3.3 ml of NH_4OH*
Dissolve $K_2CrO_4.5\ H_2O$ to a total volume of 660ml.

Solution 3:

Measure 1.65 g of $CoSO_4$-7 H_2O
Dissolve $CoSO_4\ H_2O$ in 300 ml of distilled H_2O
Add H_2O to a total volume of 330 ml.

Make 100 ml of each Roman-numeraled mixture as directed by the table. Divide the 100 ml of mixture into four 25 ml vials. Seal each vial. Number each vial with appropriate Roman numeral. The Turtox #315A57-D is an adequate vial size and type. Compile 4 sets of the vials. In order that the continuity of a set will not be broken, it is suggested that a wooden rack be fabricated so that the entire set of vials is visible while reading one. Place in the order of ascending Roman numerals, two racks of eleven vials to make one set. Be sure that the Secchi disc is visible while seeing each vial.

*The NH_4OH required is made by adding 50 ml of concentrated NH_4OH to 75 ml of distilled H_2O.

Table of Composition of each Solution in ml

Solution	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
1	100	98	95	91	86	80	73	65	56	46	35
2	0	2	5	9	14	20	27	35	44	54	65
3	0	0	0	0	0	0	0	0	0	0	0
	Blue		Greenish blue		Bluish green				Green		

Solution	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI	XXII
1	35	35	35	35	35	35	35	35	35	35	35
2	60	55	50	45	40	35	30	25	20	15	10
3	5	10	15	20	25	30	35	40	45	50	55
		Greenish yellow				Yellow				Brown	

To prepare the mixtures, put solution 1 in first; then 2; and then, 3; as indicated.

Duplicate the activity pages. One set is recommended per student. The first section of the activity serves as background and is an introduction to turbidity. This activity depends upon access to water, whether in the ocean or in a river, lake or pond. This activity lends itself well to a field excursion in which a battery of activities are planned. Plan to devote some time to a discussion of the activity and the analysis and interpretation sections. Be sure that students record the depth as the disc disappears and as it reappears when raised and lowered slowly.

KEY

Text Questions

1. Oceanographers are interested in turbidity because of its effect on primary production by plants. Turbidity is also studied for information about sediment movement and the deposition of fine silts and wastes.

2. Blue would be a good color for a fish wishing to blend into the surroundings in the deep lighted zones of the ocean. Odd as it

may seem red would also be a good color for these fish. This stems from the fact that as light penetrates deep into the sea, the red end of the visible spectrum is totally absorbed and only the deep blue wave lengths are reflected back to the surface.

3. As you increase the number of suspended particles, the amount of light seen from the side increases (more is scattered) up to the point where the scattering is so severe that the original light source is no longer visible.

4. The deeper the depth at which the object can no longer be seen, the less turbid the water. (shallow depth = more turbidity)

5. Either "deeper" and "less" should be crossed out or they should remain. Either will give a correct statement.

6. Ultra-clear waters are referred to as "marine deserts" because of the low plankton numbers which result in a correspondingly low number of other organisms.

Analysis and Interpretation:

1. Answers depend upon field results.

2. Oceanographers use the "Turbidity Factor" so that they have a standard for comparison which enables them to compare results obtained by different workers in different parts of the world.

3. The occurrence is unlikely because a depth of 7.5 meters indicates a very clear water while a shade XX brown is a very turbid water. One would not expect to find these conditions obtaining simultaneously.

4. A turbidity contour could give information on the distance sediments are carried from rivers, it could give information on the productivity of a given area, or it could be used to trace the flow of turbid effluents from industrial sites.

5. An hourly sampling would show changes due to changes in river inflow, waste inflow, tidal flow, or vertical migration of plankton among others.

6. One possible reason for the abundance of organisms in shallow water might be that the concentration of phytoplankton growth in the shallow lighted zone allows for a higher concentration of other organisms.

7. You would expect to find the greatest turbidity near rivers with a large outflow of silty water. The middle of the ocean is probably the least turbid location.

8. A standard candle is placed behind the water sample (in a standard sized container). The photographic light meter (also a standard sized model) is placed in front of the container and the transmittance is recorded. Water samples from Secchi disc sites would be tested with the new procedure until a comparison chart was constructed.

9. Fish change in response to the selective environmental pressures from the light in their surrounding habitats.

10. Light penetration is generally less than 200 meters in the deep oceans. A recording photometer is lowered and the results are observed. You could also lower photosensitive paper encased in glass to different depths and then expose to determine the extent of the lighted zone.

KEY WORDS

absorbed

benthic

diffusion

embryo

filtering

Forel-Ule Scales

hydroplane

infrared

light penetration

phytoplankton

production

quadrants

reflected

refracted

scattered

Secchi disc

silt

solutions

standard

transmittance

transmitted

transparency

turbidity

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TURBIDITY

Life in the ocean depends largely upon the growth of microscopic green plants called phytoplankton. The growth of these green plants depends on sunlight. The amount of food produced in the ocean, then, is limited by the light penetration. Where light penetration is low, production of food is also low. What factors reduce light penetration?

Moving water can carry fine dirt particles called silt. The suspended silt reduces the amount of light that can penetrate the water. Suspended silt is highest in ocean regions near the mouths of large rivers. Oddly enough, the growth of phytoplankton also reduces the amount of light penetration. High growth of plankton at the surface reduces light penetration to lower depths. The "clarity" of the water is referred to as turbidity.

1. Why would an oceanographer be interested in turbidity?

Turbidity is the opposite of transparency. These are physical properties of water. When light enters water from air it is reflected, refracted, absorbed, scattered and transmitted. A beam of light passing through pure H_2O has almost total transmittance. In order to detect this light, the beam needs to be pointed toward the receiver (you). The same is true for "true solutions" (water in which the substance is actually dissolved), although the beam of light may now appear colored. This selective absorption by color is called filtering.

Why do underwater color photographs always seem to appear blue? Why do marine animals, who normally dwell in deep water, soon die in shallow containers? Both questions can have the same answer:

The infrared, red, orange and yellow light frequencies are filtered (absorbed) in the upper water levels. The blue light frequencies penetrate the deepest. Thus, the light available for photography is blue. In a shallow container, an animal from the "blue deep" is placed in a red to yellow environment. The animal may be partially blinded by the amount and color of light. His enemies now find him an easy prey.

2. What might be a good color for a fish that wants to hide in the deep lighted zone of the ocean?

Materials in the water that are not dissolved, but are held in suspension, produce a milky appearance. A light beam is scattered so that it can be seen from any angle. Each tiny particle reflects a minute bit of light. Since the particles are randomly oriented, the beam shows from every angle. Light that is apparent at the side angles is therefore subtracted from the light arriving at the aimed destination.

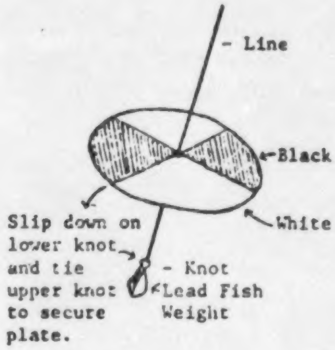
3. As you increase the number of suspended particles, what happens to the amount of light that you can see from the side?

When enough suspended particles are between the source of light and the receiver of light, the object is no longer seen. If an object is lowered underwater until it can no longer be seen (the vanishing point), the depth at which this takes place is related to the turbidity of the water.

4. How is the depth at which the object can no longer be seen related to turbidity?

5. The (deeper/shallower) an object is when it disappears, the (more/less) turbid the water is. (Cross out the words that do not belong.)

A device based on the concept of the vanishing point was developed and first used in 1865. The apparatus, called the Secchi disc, is shown below. Even today, it is in use for measurements by oceanographers around the world.



Secchi Disc

Is there a biological significance to turbidity? An emphatic YES! Egg laying species depend upon the waters to remove carbon dioxide (CO_2) by diffusion and to provide oxygen (O_2) for absorption by the developing embryos. If these eggs are covered with a layer of silt, clay or industrial waste, the embryo development stops. In turbid waters, benthic (bottom dwelling) invertebrates that feed by "pumping" water have slower growth rates. In very turbid waters, the bottom dwellers may die.

While marine plant productivity is decreased with less light, turbidity caused by a high plankton count is often an indicator of a very favorable environment. Plankton are the foundation of the marine food chain.

6. Why are ultra-clear waters often referred to as "marine deserts"?

In this activity you will measure the turbidity of water and perform a color analysis of water with the Forel-Ule Scale and the Secchi disc.

Materials:

Secchi disc

Forel-Ule color scale

maps

field notebook

Procedure:

A. To measure the turbidity of water.

1. The point of entry of the Secchi disc into H_2O should be in a shadow during a sunny day. Reflected sunlight on the surface obscures the vanishing point of the Secchi disc. There are those who can see a "sharper" vanishing point with the alternate white and black quadrants up. There are others who can do better with the white side uppermost. Try both.

   Lower the Secchi Disk into the water and RECORD the distance from the surface of the water to the disk at the point at which the disk just disappears from view.

   Raise the disc to the point at which the disc just reappears. RECORD the distance from the surface of the water to the disc in meters.

2. Determine the average distance between these two values. RECORD.

3. Repeat the procedure two more times as above. If the results for the three trials are different, average the results.

4. Move to next site. Repeat readings of underwater chain length. (Caution: The Secchi disc tends to "hydroplane" when the current is strong. Make all readings when the chain is vertical.)

5. If other analyses are to be done back at the lab, a bottled water sample should be taken at each Secchi reading site.

B. To perform a color analysis with the Forel-Ule Scale and the Secchi disc.

1. Since the color of water changes as the turbidity increases, we should be able to measure the turbidity indirectly by comparing the color of the water to vials of standard colored water. The Forel and Ule Scales are vials of colored water.

   Immerse the Secchi disc with the white side up. Lower the disc to a total depth of one (1) meter below the water's surface. Again, direct light reflections are to be avoided

2. Hold the scale at arm's length so as to see both the Secchi disc and the Forel-Ule Scale.

3. Next, read and RECORD the color closest to the color of the water (H_2O) over the disc.

4. Move to next site. Repeat the above procedure and RECORD the results.

Analysis and Interpretation:

1. The value you have determined in the field represents the lowest level of visible light returning back through the water. In reality, light penetration is deeper.

   To compare measurements obtained throughout the world, oceanographers convert the value (average length) into what is called the Turbidity Factor. This value is the relationship between the distance the light traveled through the waters at a given station to the distance it would have traveled through distilled water under similar light intensity.

   Calculate the Turbidity Factor for your results, using the following formula:

$$\text{Turbidity Factor} = \frac{1.7}{\text{Average Distance}}$$

2. Why do oceanographers use the "Turbidity Factor" rather than their original measurement?

3. If a chart of the area sampled is available, plot the Secchi disc readings on the chart. If both chain length and color are read, a plot is made in the form of an ordered pair: (7.5,XX). This indicates that the disc "disappeared" at 7.5 meters and the water was a shade XX of brown - an unlikely occurrence. Why?

4. Why might an oceanographer be interested in connecting similiar Secchi disc readings with a continuous line similiar to the contour line of a relief map?

5. What information might be gathered by taking readings at a single spot every hour during a day?

6. What is one possible reason that you might find lots of plants and animals in a shallow water area?

7. In which bodies of water would you expect to find the greatest degree of turbidity? The least?

For Further Thought..............

8. How could a photographic light meter be used on bottled water samples? How could a comparison be made with the Secchi disc field readings? (Hint: Did you ever candle an egg?)

9. Is there a conspicuous color change of fishes with an increase in depth? How do you account for this?

10. How deep does light penetrate into the ocean depths? What technique(s) can be used to verify the presence of light at a given depth?

TEACHER BACKGROUND - What's In The Water?

"What's In The Water?" serves as a culminating activity for the investigations into water chemistry. The qualitative tests provide material for review of the concepts dealt with in previous activities.

Duplicate the activity pages. One set is recommended per student. This activity may be performed by individual students or in small groups. Each approach has its merits and your selection will depend upon your particular class and circumstances. Before your class begins, describe the proper procedures for handling the chemicals used. To minimize problems place the chemical reagents in small, labeled dropper bottles. Caution your students not to mix the droppers. Be sure that students wear the proper protective gear and wipe up any spills as soon as they occur. Provide plenty of paper towelling for this activity. Anticipate any special problems that you might have and try to prevent their occurrence. Caution your students regarding the correct way to boil test tubes. Face tubes away, boil gently with boiling chips. You may prefer to use a hot water bath. As you discuss the questions and experimental results, use the opportunities that arise to review the concepts covered in the previous sections.

KEY

1 & 2. Answers depend upon the experimental results. Hopefully, the sea water had the most positive tests.

3. The distilled water most nearly serves as the control.

4. Usually, the tap water will have more positive tests than the distilled water. The drinking water may be "pure" in the sense that it will not spread disease but it may still be heavily laden with dissolved minerals.

5. The sea water generally has more positive results than the fresh water. This is explained by the fact that freshwater rivers flow into the sea and the minerals they carry are left behind in the oceans as the water evaporates in the hydrologic cycle. The minerals then are concentrated in the oceans.

6. The ocean might be called the "washbowl of the earth" since all of the materials that the rivers wash off the earth end up in the oceans.

KEY WORDS

acetic acid
ammonia
analyze
barium chloride solution
calcium
chlorides
concentrated
control
diluted
distilled
elements
hydrochloric acid
nitric acid
organic matter
pH paper
positive
potassium hydroxide solution
potassium permanganate solution
precipitate
qualitative
quantitative
sea water
silver nitrate solution
sodium carbonate solution
standard
sulfates
sulfuric acid
tap water

WHAT'S IN THE WATER?

What are some of the more common elements found in sea water? In this investigation you will have a chance to determine an answer to this question. The tests you will be doing are qualitative tests. A qualitative test tells you whether something is present or not, it does not tell you how much of the substance is present. The "how much" is determined by quantitative tests which require special techniques.

Be careful as you perform these tests. Wipe up any spills immediately and avoid contact with any of the solutions, especially the concentrated acids. Be sure to clean your test tubes thoroughly between tests.

Materials:

wax pencils
test tube clamps
test tube holders
3 test tubes
alcohol burner or heat element
safety glasses or goggles
lab apron
sea apron
sea water
tap water
distilled water
boiling chips

Chemicals for analysis

Acetic acid (172 ml glacial acetic acid diluted to 1000 ml.)
Sodium carbonate solution (159 g Na_2CO_3 diluted to 1000 ml.)
Hydochloric acid (3N; 258 ml of 36% HCl diluted to 1000 ml.)
Barium chloride solution (61 g $BaCl_2$-$_2H_2O$ diluted to 1000 ml.)
Nitric acid (3N; 195 ml of 69% HNO_3 diluted to 1000 ml.)
Silver nitrate solution (85 g A g NO_3 diluted to 1000 ml.)
Potassium hydroxide solution (176 g KOH diluted to 1000 ml.)
Potassium permanganate solution (1g diluted to 1000 ml.)
Sulfuric acid (concentrated)
pH paper, litmus paper, methyl orange or phenolphthalein (for acidity and alkalinity tests.)

Procedure:

1. As you analyze your samples of water, record your results in the chart below.

2. Mark your test tubes so that you are always using the same one for sea water, the same one for tap water, etc.

3. For each test, first fill your test tube 1/2 full of the water (about 10 ml) sample you are testing.

4. These tests do not have to be done in any special order. In fact, if you do them out of order you will avoid getting bogged down waiting for a chemical everyone else is using. Note that a positive reaction means that the substance you are testing for is present.

Tests for:	Description of results of tests for:		
	Distilled Water	Tap Water	Sea Water
Calcium			
Sulfates			
Chlorides			
Ammonia			
Organic matter			
pH.			

5. Clean all glassware and your work area.

Tests:

Calcium - To 1/2 test tube of water sample, add three drops of acetic acid and three drops of sodium carbonate. Record what you observe in each test tube and put your observations in the chart. (White precipitate means positive: i.e. there is calcium in the water)

Sulfates- To each test tube of water, add three drops of hydrochloric acid and 2 boiling chips. Heat to boiling (slowly over an alcohol burner or element). Then add 3 drops of barium chloride solution. Record the results. (White precipitate means positive.)

Chlorides - To each test tube add 3 drops of nitiric acid and 3 drops of silver nitrate solution. Record the results. (White precipitate means positive).

Ammonia	- To your water sample add 4 drops of potassium hydroxide and heat gently. Cautiously sniff the test tube and smell the fumes. Record results. (Ammonia smell means postive).
Organic	- To your sample add 2 drops of potassium permanganate solution and 5 drops of concentrated sulfuric acid. Heat to boiling and record any change. (Purple changing to brown means positive.)
pH	- To test if your water is acidic or not, touch a piece of litmus paper to it and record color of wet end (pink means acid, blue means base).

Analysis and Interpretation:

1. Which type of water had the most positive tests?

2. Was any test positive for all three types of water?

3. Most experiments have a control. The control serves as a standard against which you can compare your results. Which type of water most likely serves as a control in this investigation?

4. How did the results of the tests on tap water compare with the results from the distilled water? How "pure" is your drinking water?

5. Was there a difference in the results of the tests on fresh water and sea water? How can you explain your results?

6. The ocean has been called the "washbowl of the earth." Why might this be a good description of the ocean?

SEND-IN PAGE

Well, you've made it. Thank you for teaching about the marine environment. We worked hard to put this unit together and we would really like to hear from you. If you have any reactions (positive or negative) that could help us, please let us know. We are also interested in any changes you made in the activities which you feel made them more useful. If you have some marine activities that you have tried successfully with children, we would like to know about them also. Perhaps we can help you share your working ideas with other teachers concerned with the marine environment. Again thanks, and keep up the good work.